TARMAC

UNDERFLOOR HEATING WITH THERMALLY CONDUCTIVE SCREEDS

SOLUTION GUIDE

SOLUTION GUIDES

CONTENTS

Introduction	8
Reference project	9
Technical description	11
System performance	15
On-site implementation	25
Environmental improvements	27
Our sustainability strategy	31
References	32

GLOSSARY

Thermal Comfort
Describes a person's state of mind in terms of whether they feel too hot, too cold or just right[1].

Hydronic Underfloor He ting
A heat transfer system based upon a network of pipes which utilises water as the medium for heat transfer.

Radiant Heat Transfer
The transfer of heat, via to infra-red radiation, from a warm object to that which is of a lower temperature with a direct line of sight 2 .

Convective Heat Transfer
Heat transfer which occurs within gasses and liquids, as it is warmed it rises, falling as it cools to create a convection current[3].

Conductive Heat Transfer
The transfer of heat from a warm object to a cool object which is in direct contact[3].

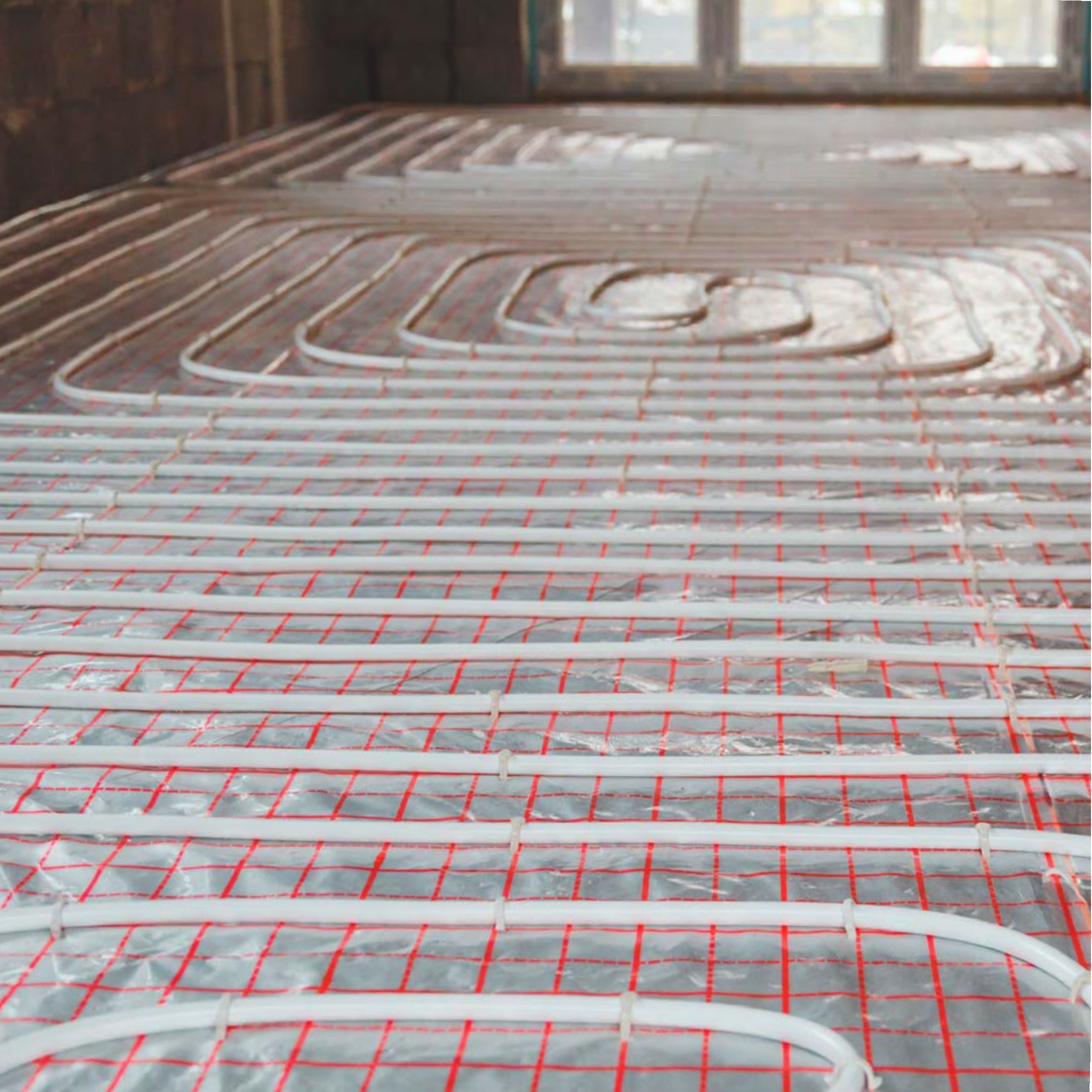
Thermal Conductivity (λ) (W/mK)
The measure of heat fl w through a specific m terial which is independent of thickness (the greater its λ the greater its conductivity)[4].

Thermal Transfer Coefficient (U)
Thermal Resistance (R)
U (W/m^2K) and R (m^2K/W) values represent the insulating properties of construction materials. The U value is the reciprocal of the combined R values of a building element based upon its constituent components. U values describe the rate of heat loss through a unit area of an element, the lower a U value the lower the heat loss. R values describe the level of resistance to heat transfer within a specifi component, where R increases so does resistance and insulating properties[5].

Expanded Polystyrene (EPS)
A rigid cellular plastic, which can be formed into a multitude of shapes for a range of applications.
It is formed through the expansion of gases within polystyrene beads and used as insulation due to its low thermal conductivity[6].

Extruded Polystyrene (XPS)
A closed celled plastic formed through a continuous extrusion process of melted polystyrene injected with a blowing agent. On exiting through the extruder die the change in pressure results in the expansion of the material to form an insulating board[7].

Coefficient of erformance (COP)
A ratio used to measure the effectiveness of conversion of input energy to useful output energy. Heat pumps can achieve a COP of 4, where 1 unit of input energy (typically electrical) can be converted to 4 units of heating or cooling energy[8].



Our approach to construction encompasses innovative sustainable products, efficient building systems and practical solutions. We recognise the important role we have in promoting sustainable construction by optimising our products, their use and whole life performance. This document is one of a suite that identifies specific construction solutions that can help deliver a sustainable built environment. They explore the details of each system, its performance benefits, how it can be implemented in a project and then compares its environmental performance against alternative solutions.

This document introduces underfloor heating with thermally conductive screeds, which contribute to the construction of buildings that are responsive, efficient, long lasting and robust.

Typical Applications

Any internal floor.

INTRODUCTION

Underfl or heating systems offer improvements in energy efficiency and the thermal comfort of users when employed as a replacement for conventional heating systems.

There are two distinct systems for underfloor heating, either electric based or hydronic based. A hydronic system consists of a network of pipes containing water and antifreeze. This system unlike an electric solution can be used for both heating and cooling operations.

An underfloor system with a high thermally conductive self-compacting anhydrite screed provides improvements over conventional screed or slab construction systems. Increased thermal conductivity reduces reaction time and the flowing nature of a self-compacting screed results in an improved pipe coating, enhancing the pipe/screed interface, which combined with guaranteed homogeneity can further improve thermal energy transfer. The inherent strength, durability and low shrink characteristics of anhydrite screeds enables depths to be reduced without compromising performance.

Location: Cambridge

Client: Berkeley Homes

Sub-contractor: Screed and Stone

Year: 2012

Development: Mixed apartments and townhouses

CAMBRIDGE RIVERSIDE

Set on the banks of the River Cam the Berkley Homes development is comprised of a mix of residential offerings from studio to three bedroom apartments along with several townhouses.

Berkeley Homes engaged and challenged their screed contractors, Screed and Stone, along with Tarmac, to optimise and enhance the underfloor heating and screed system. The proposed, and implemented, system utilised Topflow Screed A, resulting in a thinner screed layer, bringing the pipe network closer to the surface, minimising response time, and the ability to increase insulation thickness minimising losses.

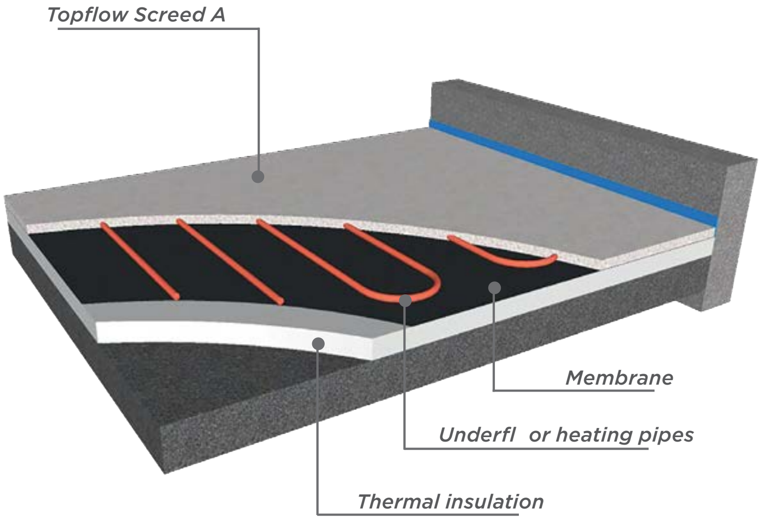
Thermal performance improvements were all achieved within the depth of a traditional sand cement screed. The flowing and self-compacting nature of Topflow Screed A, combined with its reduction in depth to 50mm (compared to a traditional sand cement screed), enabled significant gains to be made in placement time. The largest floors consisted of a screeded area of approximately 1,000m^2, with Topflow Screed A it was possible to complete this within one working day, where sand cement screeds are limited to approximately 100-150m^2/day.

The adoption of this solution enabled the main contractor's strict time constraints to be adhered to, with each floor completed within a week period. Two days were required for preparation, placement of insulation and slip membrane, two days for laying out the underfloor conduit and a single day for screed placement. A material saving of 25m^3 was made on the largest floors (1,000m^2) due to the depth reduction and the delivery of the material in its fresh state minimised site processes and storage demands associated with traditional sand cement screeds.

An underfloor heating system is comprised of a network of pipes laid and installed within the floor structure of a building[9].

In a hydronic system a network of pipes conveys hot water from the heat source, in a closed loop throughout a building where the water is cooled via heat exchange with the screed.

As the screed is heated it discharges this energy to the room primarily through radiation, but also through convection and conduction. The returned water is then reheated to operating temperature and re-circulated through the system[9].



Topflow Screed A
Membrane
Underfl or heating pipes
Thermal insulation

The layout of the pipe network is dependent on room design and external openings with a requirement to balance out heat losses at external openings by increasing pipe density[10].

Thermal comfort is maintained through radiated heat transfer and the system, when compared to radiators can operate at a significantly reduced temperature when compared to radiators (21 - 25°C from 80°C[10,11]).

For an underfloor heating system to match the thermal comfort provided by radiators maintaining a room temperature of 22°C the underfloor heating system is only required to heat the room to 20°C. This reduction in temperature is a result of the location of the heat source (floor compared to wall) and a change in heat transfer methods (underfloor systems emitting more energy via radiant heat transfer).

Reducing operating temperatures reduces the demand on heat sources and increases the opportunities to implement alternative heat sources; air or ground source heat pumps, solar thermal or biomass, offering high efficiencies and further reducing external energy demands[12].

Hydronic systems, dependent of the heat source, can also be utilised for cooling in periods of high temperatures[13].

TOPFLOW SCREED A

Topflow Screed A is a self-compacting screed which is based around the application of a synthetic calcium sulphate binder, in lieu of cement, special additives and selected aggregates.

It displays zero curling and offers minimal shrinkage, providing the capacity to place slabs up to 1,000m^2 without joints or up to 300m^2 over underfloor heating without joints.

The inherent strength of the product (compressive and flexural strength of 25 N/mm^2 and 4 N/mm^2 respectively) enables thinner screeds to be placed.

It is also well suited to heating systems in light of its relatively high thermal conductivity (2.2 W/mK), which is twice that achieved with traditional sand and cement screeds.

A further advance is Topflow Screed A Thermio which offers an even greater thermal conductivity of 2.5 W/mK.

ENERGY EFFICIENT

Underfloor heating systems offer the ability to reduce energy demands and improve heat supply efficiencies, whilst utilising renewable and more sustainable heat sources[12]. Equivalent levels of thermal comfort can be achieved at lower operating temperatures when compared to radiator systems[10,11].

COMBUSTION BOILERS

The reduction in the heating demand of underfloor heating systems and their ability to utilise low temperature heat sources does not preclude the use of conventional, combination and condensing, boilers. Biomass boilers can be used as direct replacements for gas boilers, burning natural wood, chips or pellets. Wood burning is considered low carbon, as it is only the carbon absorbed during its life and through transport and handling which is released however it is only sustainable as long as replacements are grown in place of those used[14].

HEAT PUMPS

The low operating temperatures of underfloor heating systems are fundamental drivers for the ability to utilise heat pumps as heat sources[15,16]. Output temperatures range between 30-45°C which are ideal for underfloor heating, and where they perform most efficiently delivering a COP of about 3. The high COP enables energy savings to be made as the energy output is greater than the energy cost to run the system, as heat energy is drawn from the operating environment[17].

SOLAR THERMAL

It is not recommended that solar thermal heat sources are used as a sole heat source for underfloor heating systems. Whilst they are capable to support a small scale underfloor heating system, they are most effective if combined with complementary heat sources to mitigate any output drops[20].

Boilers and heat pumps can form part of a compatible system which utilises a solar heat store as the interface[20].

A solar thermal system can be used as a preheater, reducing energy demands for the underfloor heating whilst satisfying a larger percentage of hot water needs[21].

IMPROVED REACTION TIME

The use of an anhydrite screed in place of a traditional sand cement screed can offer significant improvements in heating response times.

Improvements in thermal conductivity over sand cement screeds increases the speed at which heat energy moves through a material, where Tarmac's Topflow Screed A has a thermal conductivity twice that of traditional sand cement screeds.

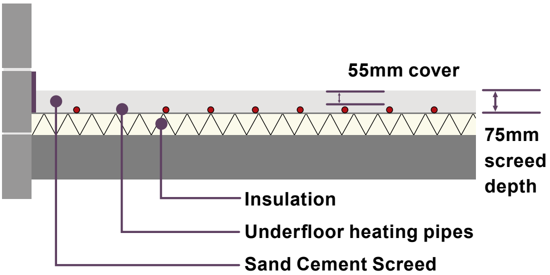
The flexural and compressive strength of anhydrite screeds allows a thinner layer of screed to be placed reducing cover to pipes compared to traditional sand cement screeds This is illustrated in the diagrams on the next page.

The reduction in cover and increased thermal conductivity enables the system to respond quicker to the occupant requests and maintain thermal comfort.

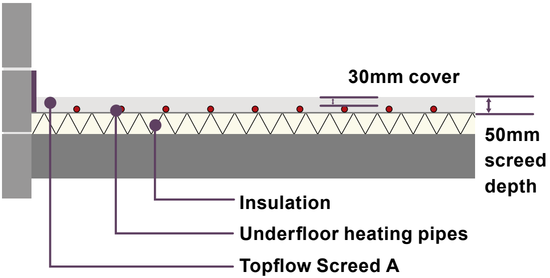
HOMOGENEITY

A self-compacting screed can improve the homogeneity of a flooring solution due to its flowing nature and its ability to obtain full compaction without the need for any external energy input [22]. Where full compaction is achieved this will facilitate the complete envelopment of underfloor heating pipes, improving heat energy transmission, complimenting thermal conductivity and the systems ability to respond to occupants' requirements.

The homogeneity of sand cement screeds are dependent on the skill level and physical strength of the operative carrying out the compaction operation. It is inherently difficult to determine the level and quality of compaction when carried out through manual methods,which if not complete can have a detrimental effect on system performance[23]. Any pockets of entrapped air will act as insulators slowing heat transfer due to its reduced thermal conductivity when compared to screed (air conductivity is 0.024 W/mK compared to 2.2 W/mK for Topflow Screed A and 2.5 W/mK for Topflow Screed A Thermio).



Section through a sand cement based screed underfloor heating solution



Section through a calcium sulphate based screed underfloor heating solution

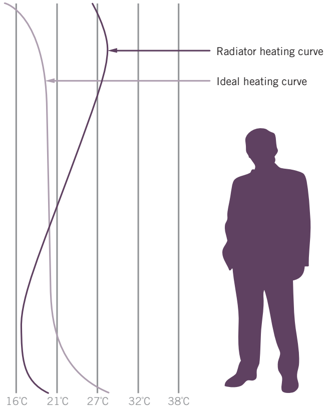
INCREASED THERMAL COMFORT

Thermal comfort is defined as the 'condition of mind which expresses satisfaction with the thermal environment' [1] or in simpler terms whether someone is feeling neither too hot nor too cold. It is a balance between the conditions of the inhabited room and the heat losses of its occupants.

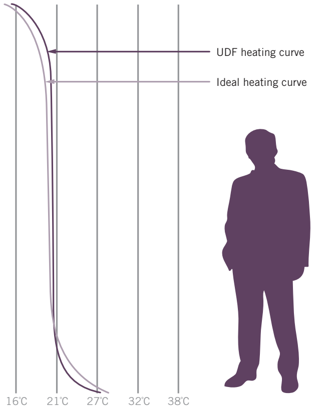
An ideal heating curve for thermal comfort has been described in many industry publications, it is based upon the ideal temperature of the human body at different heights, as a factor of the heat losses experienced across the human body (illustrated on the next page)[†]. Comfort is influenced by air temperature and the radiant temperatures of objects within a room along with the walls, floor and ceiling [24].

When compared to radiators, underfloor heating provides a heating curve that is more closely aligned to the ideal heating curve than that of radiator based systems. This is due to the floor acting effectively as a large radiator, radiating the heat directly to occupants, where as a traditional radiator system heats primarily via convection [10].

Underfloor heating can avoid issues of draughts and cold spots that can occur through radiator heating and it is also possible to attain the same level of thermal comfort at a lower temperature [25].



Radiator heating curve compared to ideal heating curve†



Underfloor heating curve compared to ideal heating curve†

† Adapted from The Portland Cement Association[28], Viege[29] and Uponor[30]

HIGH RECYCLED CONTENT

The primary active component of Topflow Screed A, calcium sulphate ($CaSO_4$), is a by-product of hydrofluoric acid production which was previously sent to land landfill.

Utilisation of this waste enables significant reductions in embodied energy to be made as the binder has already been produced requiring minimal further processing and avoiding the high energy processes associated with cement production. Topflow Screed A has a final recycled content of 36% with the binder itself being 98% recycled[26,27].

IMPROVED INSULATION CHOICE

Within underfloor heating systems screed thickness can be reduced by employing an anhydrite screed in place of a traditional screed. Where predetermined formation levels are maintained changes can be made to deliver improved performance or reduced cost by balancing insulation performance and layer thickness.

Opportunities for cost savings can be made through using a thicker layer of more inexpensive lower performing insulation or improving performance by using more of existing insulation.

The table opposite details the relationship between desired U value, insulation type and insulation depth, which can be used to demonstrate the aforementioned approach.

			P/A RATIO*								
			1.00	0.90	0.80	0.70	0.60	0.50	0.40	0.30	0.20
MATERIAL	THERMAL CONDUCTIVITY (W/mK)	STRENGTH (KPA)	INSULATION DEPTH (MM)								
EPS 100	0.035	100	165	160	160	155	155	150	140	125	100
EPS PLATINUM	0.030	100	140	140	140	135	130	125	120	105	85
XPS	0.029	200	135	135	135	130	125	120	115	100	80
POLYURETHANE WITH FOIL	0.023	130	110	110	105	105	100	100	90	85	65
PHILONIC POLYURETHANE WITH FOIL	0.021	140	100	100	95	95	95	90	85	75	60

Comparison of insulation depth and insulation type to achieve a U value of 0.18 W/m^2

* The P/A ratio is the ratio between slab perimeter (m) and the area (m^2) of slab enclosed by this perimeter.

FAST TRACKING OF CONSTRUCTION

Self-compacting screeds can signifi antly improve construction speeds as they employ a simplified placement methodology, can be delivered on demand and without the requirement for onsite mixing or space for storage.

The flowing nature of self-compacting screeds mean that they require less manual manipulation in placement, with time and labour intensive activities of screeding and tamping with a traditional screed avoided[31].

These properties enable a fivefold increase in area that can be placed when composed to a traditional screed enabling 1,000m^2 to be placed rather than 100-150m^2 per day.

Underfloor heating in anhydrite screeds can be commissioned after 7 days enabling the screed to be force dried, sand cement screeds can only be commissioned after 21 days.

Early commissioning enables final finishes to be applied sooner as desired moisture contents can be achieved earlier.

Simplified and less demanding placement of Topflow Screed A

Intensive placement operation of sand/ cement screed installation

The installation of underfloor heating systems with self-compacting screeds requires adherence to a number of procedures, governing pre-construction, construction and post pour activities to ensure the quality of the finished floor.

PRE-PLANNING AND INSTALLATION CONSIDERATIONS	
Underfloor heating	When an underfloor heating system is installed quality checks are required to be carried out prior to the undertaking of the screeding operation. British Standards require a pressure test to be undertaken prior to the placement of screed [32], to ensure that there are no leaks within the system which could cause failure and future issues. Checks should be made to ensure that pipes are sufficiently secured to avoid floating during installation and that a minimum cover of 30mm (to top of pipe) is achieved.
Bay size and layout	Unlike cementious screeds, calcium sulphate screeds are not subject to excessive shrinkage and expansion. It is therefore possible to redefine the equirements for bay sizes and jointing. Bay sizes can extend up to 1,000m^2, with a maximum bay dimension of 40m and an aspect ratio not exceeding 6:1. Where underfloor heating systems are employed bay sizes must be reduced to 300m^2 and joints created between heating circuits to allow for temperature, shrinkage and expansion differentials.

PRE-PLANNING AND INSTALLATION CONSIDERATIONS	
Drying time	Installation of resilliant floor coverings can only be completed once a sufficient moisture content is reached in underlying screeds, which dictates the continuation of construction works. A calcium sulphate screed, in ideal drying conditions (defined in BS 8204[33]), like a sand cement screed, can indictivly achieve a drying rate of 1mm per day up to a depth of 40mm, followed by a rate of 0.5mm per day. Calcium sulphate screeds offer a reduced drying time due to reductions in screed depth enabling follow on trades to commence sooner. This is illustrated in the table on p25. Drying times can be further reduced by improving the drying environment, through the use of dehumidifiers and/or space heaters or through force drying by commissioning the underfloor heating system (guidance for forced drying should be sought from product manufacturer). Prior to the application of subsequent finishes it is necessary for the moisture content of the floor to be established and according to British Standards this should be no higher than a relative humidity of 75%[35].
Subsequent finishing	Cementitious based adhesives should be avoided when using calcium sulphate screeds due to the potential for deleterious chemical reactions. This issue can be addressed through the use of suitable surface primers which stop material interaction and moisture transmission can be used or specially formulated calcium sulphate adhesives should be used (adhesive producers guidelines should be followed at all times).

		DRYING TIME		
SCREED	DEPTH (MM)	DEPTH AT 1MM PER DAY DRYING RATE (MM)	REMAINING DEPTH AT 0.5MM PER DAY DRYING RATE (MM)	
SAND AND CEMENT	75	50	25	100
TOPFLOW SCREED A	50	40	10	60

Comparison of drying time durations of sand cement and calcium sulphate screeds

SUSTAINABILITY

When underfloor heating systems using thermally conductive anhydrite screeds are selected in place of sand/cement and radiator based solutions further environmental improvements can be delivered.

MATERIAL EFFICIENCY

Utilising Topflow Screed A underfloor heating solution over traditional cementitious screeds such as sand/cement allows for improvements in material efficiency whilst maintaining performance. Topflow Screed A's ability to be laid thinner and incorporate waste material enables less material to go further, which can provide significant savings on the project scale.

RESOURCE DEPLETION

The use of finite resources is a key issue when considering the selection of construction materials and solutions. Topflow Screed A performs well in this regard due to its use of calcium sulphate, a waste product from hydrofluoric acid production, this results in a recycled content of 36% that reduces demands on finite virgin materials.

PRIMARY AND EMBODIED ENERGY

With the incorporation of a waste and a reduction in material depth a Topflow Screed A solution offers reductions in primary and embodied energy. The calcium sulphate binder, unlike cementitious binders, requires little or no processing, reducing embodied energy while production energy is also reduced as due to decreases in material quantities for construction.

RECYCLING

The concrete industry has taken significant steps to improve its performance in terms of material reuse, reducing the depletion of abiotic resources, increasing energy efficiency and reducing carbon emissions. Significant improvements have already been achieved compared to the industry's 1990 baseline[36].

With respect to material reuse and the depletion of abiotic resources, concrete readily utilises recycled and secondary materials along with cement replacements. This has enabled the industry to be a net user of waste, using 47 times more waste than it generates[36], and concrete itself is also 100% recyclable[37].

BES 6001*

Tarmac has achieved an 'Excellent' rating for all its production sites and products. The independent third-party scheme assesses responsible sourcing polices and practices throughout the supply chain[38].

ISO 14001

Tarmac are fully accredited with ISO 14001, having implemented Environmental Management Systems throughout our business, maintaining our commitment to reducing our environmental impact[39].

SUSTAINABILITY ASSESSMENT SCHEMES

Screed can play an extended role in enabling an efficient building to be created and can contribute in a number of assessment schemes and help achieve a range of credits‡.

CREDIT/TARGET	BREEAM	LEED
	Man 03: Responsible Construction Practices Tarmac's Carbon Calculator has the capability to determine and provide data relating to the CO_2 arising from the delivery transport.	**EA Credit 1: Optimize Energy Performance** Due to low operating temperatures energy demand is reduced and renewables can be utilised.
	Hea 04: Thermal Comfort Underfloor heating systems and the radiant heat transfer provides an effective basis for heating and cooling strategies. Systems can be easily zoned to match varying demands within a building.	**MR Credit 4: Recycled content** Calcium sulphate screeds utilise industry by-products that would otherwise be sent to landfill.
	Ene 01: Reduction of energy use and carbon emissions This system can reduce energy demands by lower operating temperatures and can facilitate the utilisation of renewable energy sources.	**MR Credit 4: Regional materials** Ready mixed materials are primarily produced from locally available materials.
	Mat 03: Responsible sourcing of materials Ready-mixed products are primarily constituted of locally available materials. All ready-mixed products produced by Tarmac are BES 6001 accredited.	**IEQ Credit 6.2: Controllability of Systems - Thermal Comfort** Underfloor heating systems are highly controllable with the ability to have individually controlled zones.
	Wst 02: Recycled aggregates Calcium sulphate screeds make use of an industry waste product, resulting in a minimum recycled content of 36%.	

‡ Tarmac concrete products offer the ability to conform with a wide-ranging number of assessment criteria in both BREEAM and LEED. For more information contact Tarmac sustainability team.

* Our BES 6001 certificate number for our readymix concrete products is BES 559207.


PEOPLE
Safety and health
Our people
Community involvement


PLANET
Climate change
Environmental stewardship
Resource efficiency


PERFORMANCE
Economic value
Governance and ethics
Communication


SOLUTIONS
Sustainable supply chain
Innovation and quality
Sustainable construction

OUR SUSTAINABILITY STRATEGY

Sustainability is about securing long-term success for our business, customers and communities by improving the environmental, social and economic performance of our products and solutions through their life-cycle. This means considering not only the goods we purchase, our operations and logistics but also the performance of our products in use and their reuse and recycling at the end of their life. By doing this, we can understand and take action to minimise any negative aspects, while maximising the many positive sustainability benefits our business and products bring.

Using this 'whole life' thinking we have engaged with our stakeholders to develop our sustainability strategy. The strategy defines the main sustainability themes and our key priorities, those issues which are most important to our business and our stakeholders. It sets out our commitments to transform our business under four main themes: **People, Planet, Performance and Solutions**.

Building on progress already made, we have set ambitious 2020 milestone targets for each of our key priorities. These ambitious targets have been set to take us beyond incremental improvement programmes to business transforming solutions.

FOUR THEMES

Twelve key priorities

Twelve commitments

Twelve 2020 milestones

Forty four other performance targets

Our 2020 milestones are supported by a range of other performance targets. This hierarchy helps make it easier to build understanding, drive improvement and enables us to report progress in a meaningful and measurable way.

REFERENCES

1. **Health and Safety Executive – Thermal Comfort**
   www.hse.gov.uk/temperature/thermal/index.htm
2. **US Department of Energy – Radiant Cooling**
   www.energy.gov/energysaver/articles/radiant-cooling
3. **US Department of Energy – Heating & Cooling**
   http://energy.gov/public-services/homes/heating-cooling
4. **The Energy Saving Trust Technical Guidance – CE 71: Insulation Materials Chart**
   www.energysavingtrust.org.uk
5. **RIBA Sustainability Hub, U values**
   www.architecture.com/SustainabilityHub/Designstrategies/Earth
6. **The BPF Expanded Polystyrene Group**
   www.eps.co.uk/abouteps/attributes.html
7. **European Extruded Polystrene Board Inuslation Association**
   www.exiba.org/what_is_XPS.asp
8. **The Energy Saving Trust, Getting warmer: A field trial of heat pumps, London, 2010**
   www.heatpumps.org.uk/.../TheEnergySavingTrust-GettingWarmerAFieldTrialOfHeatPumps.pdf
9. **Sport Scotland – Facilities Report 02: A designers guide to underfloor heating in sports halls 2008**
10. **GreenSpec® - Refurbishment / Retrofit: Radiators and Underfloor Heating**
    www.greenspec.co.uk/radiators-underfloor-heating.php
11. **Underfloor Heating Manufacturers Association - Underfloor Heating**
    www.beama.org.uk/en/energy/underfloor-heating/
12. **The Energy Saving Trust – Choosing a renewable technology**
    www.energysavingtrust.org.uk/Generating-energy/Choosing-a-renewable-technology
13. **US Department of Energy – Radiant Heating**
    http://energy.gov/energysaver/articles/radiant-heating
14. **The Energy Saving Trust – Wood fuelled heating**
    www.energysavingtrust.org.uk/Generating-energy/Choosing-a-renewable-technology/Wood-fuelled-heating
15. **Which? – Ground source heat pumps explained**
    www.which.co.uk/energy/creating-an-energy-saving-home/guides/ground-source-heat-pumps-explained/
16. **Which? – Air source heat pumps explained –**
    www.which.co.uk/energy/creating-an-energy-saving-home/guides/air-source-heat-pumps-explained/
17. **GreenSpec® - Ground Source Heat Pumps (GSHP)**
    www.greenspec.co.uk/ground-source-heat-pumps.php
18. **The Energy Saving Trust – Air Source Heat Pumps**
    www.energysavingtrust.org.uk/Generating-energy/Choosing-a-renewable-technology/Air-source-heat-pumps
19. **The Energy Saving Trust – Ground Source Heat Pumps**
    www.energysavingtrust.org.uk/Generating-energy/Choosing-a-renewable-technology/Ground-source-heatpumps

20. **Good Energy – Solar Thermal Site Selection**
www.goodenergy.co.uk/generate/choosing-your-technology/home-generation/solar-thermal/solar-thermal-site-selection

21. **GreenSpec® - Solar Hot Water Collectors**
www.greenspec.co.uk/solar-collectors.php

22. **Skarendahl, A. and Billberg, P. (2006)**
Casting of Self Compacting Concrete: Final report of RILEM Technical Committee 188-CSC: Casting of Self Compacting Concrete, RILEM REPORT 35, RILEM Publications Bagneux, France

23. **The Concrete Society/Building Research Establishment (BRE) (2005)**
Self-compacting Concrete: a review, Technical Report No.62, Report of a joint working group, The Concrete Society and BRE, Camberley, Surrey, UK.

24. **Health and Safety Executive – Thermal Comfort: The six basic factors**
www.hse.gov.uk/temperature/thermal/factors.htm

25. **GreenerHeat – Underfloor Heating**
www.greenerheat.co.uk/renewable-heating/under-floor-heating/frequently-asked-questions

26. **Gyvlon – Environmental Statement**
www.gyvlon.co.uk/page8.html

27. **Tarmac Topflow Screed A**
www.tarmac.com/#readymix

28. **Portland Cement Association, Concrete Technology Today: Radiant Heat With Concrete, Volume 18, Number 1, 1997**

29. **Viega - Concrete System: Installation Manual (2009)**
www.viega.net/cps/rde/xbcr/en-us/Viega_Concrete_Systems.pdf

30. **Uponor – Radiant Heating and Cooling Systems: Complete Design Assistance Manual (CDAM) (2011)**

31. **Rich, D. (2013)**. From reactive to proactive: quantifyingon-site benefits of self-compacting concrete (SCC), Loughborough University

32. **BS EN 1264-4: 2009, Water based surface embedded heating and cooling systems – Part 4: Installation**

33. **BS EN 8204-7: 2003, Screeds, bases and in situ floorings – Part 7: Pumpable self-smoothing screeds – Code of practice**

34. **BS EN 8204 – 1: 2003, Screeds, bases and in situ floorings – Part 1: Concrete bases and cementitious levelling screeds to receive floorings – Code of practice**

35. **BS EN 8203: 2001, Installation of resilient floor coverings**

36. **The Mineral Product Association and The Concrete Centreon behalf of The Sustainable Concrete Forum – Concrete Indusry Sustainability Performance Report 4th Report: 2010 performance data**

37. **GreenSpec® - Reducing the Impact of Concrete**
www.greenspec.co.uk/greening-of-concrete.php

38. **Green Book Live**
www.greenbooklive.com/search/scheme.jsp?id=153

39. **ISO 14001**
www.bsigroup.co.uk/en/Assessment-and-Certification-services/Management-systems/Standards-and-Schemes/ISO-14001/?gclid=CO6WrLnSgrMCFcrItAodVhwAUA

3678/1214 - FCC 0243

TARMAC

T3 Tarmac Ground Floor T3 Trinity Park
Bickenhill Lane Birmingham B37 7ES
For more details visit tarmac.com/contact

Version: March 2017

TARMAC.COM