

PASSIVE SOLAR DESIGN

SOLUTION GUIDE



SOLUTION
GUIDES

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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 and considers specific construction approaches and solutions that can help deliver a sustainable built environment. They explore the characteristics and requirements of construction

approaches and how the performance benefits of specific systems can be implemented into a project to deliver a sustainable outcome.

This document introduces Passive Solar Design as a solution that can optimise the use of a building's fabric to deliver occupant thermal comfort while reducing energy demands for its heating, cooling and lighting.



INTRODUCTION

WHAT IS DRIVING THE NEED FOR SUSTAINABLE SOLUTIONS?

The UK construction industry and users of the built environment are subject to a number of challenges that are having a significant impact on the manner in which we design, build and operate assets. Sustainability and sustainable solutions are required to be at the forefront of design, construction and operation to meet these challenges.

The UK has been subject to consistent increases in energy costs over the past decade, in both the domestic and industrial sectors. Electric and gas prices have risen by 3.3% and 2.9% respectively over the period of Q3 2013 to Q3 2014 for domestic users, whilst for industrial users gas fell by 19% (including CCL) and electric rose by 4.4% over the same period (DECC Quart Energy Prices 2014¹).

This general increase in costs reflects the historic rise of energy costs and demonstrates the UK's reliance on non-renewable energy and the scarcity of these resources.

The significance of this issue is demonstrated when the energy demands of the built environment are considered, represented as carbon emissions. The Green

Construction Board² identifies that carbon emissions from capital sources (materials and construction processes) accounts for 18% of energy consumed over a building's life. The remaining 82% of emissions are linked to the operation of the building, with the majority of energy used for heating, cooling and lighting. As focus shifts to refurbishment rather than demolition and rebuilding of assets the balance of energy use is likely to shift further towards operational use with the importance of this issue increasing.

It is expected that changes in global temperatures will drive more extreme weather resulting in an increase in energy demand for heating and cooling. Rising temperatures will increase the UK's need for the cooling of domestic properties and an increase in existing demands for commercial properties. Concerns have already been raised that existing and newly

constructed housing stock may be subject to unavoidable over heating (Zero Carbon Hub^{3,4}).

In light of these issues and in line with global and European requirements the Government has set stringent targets on the performance of new buildings, with respect to energy use and carbon. Revisions to Part L of the Building Regulations and Zero Carbon housing targets is just one of many targets and regulations which require changes to the way in which buildings are designed, constructed and operated. When heavyweight construction materials are considered the embodied energy due to their manufacturing processes means that more than just their structural characteristics need to be utilised.

Materials need to be selected with the performance and operation of the building in mind, how they contribute and optimise sustainable performance.



WHAT IS PASSIVE SOLAR DESIGN?

Passive solar design is a strategic approach to sustainable construction that utilises the fabric of a building and natural solar effects to create a comfortable environment for occupants.

Reliance on mechanical methods to satisfy heating, cooling, ventilation and and daylighting needs and their associated energy demands can be reduced through this approach.

Passive solar design requires the environment in which the building is to be situated to be considered throughout the design process. Orientation, wind direction, neighbouring structures and natural sheltering, are starting points for passive design, demonstrating that it is about more than just the building itself. Passive solar design combines natural effects, such as prevailing winds and solar energy transfer mechanisms, with intelligent design to create considerable benefits in maintaining a comfortable environment.

If considered at an early stage passive solar design can provide a valuable opportunity to improve a buildings operation, however it is vital that this forms part of an integrated holistic approach.

Passive solar design requires key principles to be adhered to in order to facilitate positive contributions to heating, cooling, ventilation and daylighting. These principles relate to physical building characteristics and the environment within which the building is placed^{5,6,7,8,9,10}.

ORIENTATION

Orientation and a clear view of the southern sky are fundamental to capturing solar gain during the heating season. In ideal circumstances main glazing elements should orientate towards the south or within 30° of south. Outside of this range effective solar gain will be reduced, compromising contributions to heating requirements. (Figure 1)

OVERSHADING

Overshading, like orientation, is concerned with the provision of a clear view of the southern sky to facilitate solar gain. Whilst it is extremely rare that a building is free from overshading steps should be taken to minimise obstructions. These can be due to the position of nearby buildings, inappropriate vegetation selection and site

topography. Site layout should take these factors into consideration and refer to sun angle which varies dependent on site latitude. (Figure 2)

SHADING

The requirement of a building to be south facing to assist with heat gain in winter can lead to excessive solar gain during summer months (see orientation). The effect of this can be poor building performance due to overheating causing a detrimental effect on occupant comfort. This risk can be reduced by employing shading which aligns with the high sun angle in the summer but does not obstruct the sun at its lowest angle during the winter, i.e. vegetation or brie solar. (Figure 3)

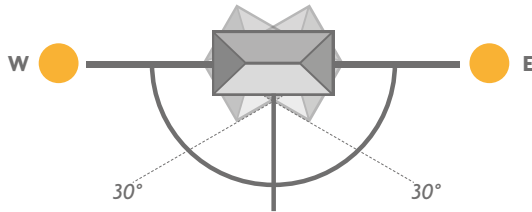


FIGURE 1
ORIENTATION

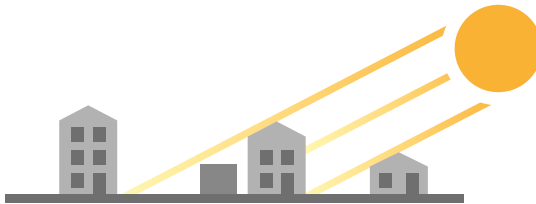


FIGURE 2
OVERSHADING

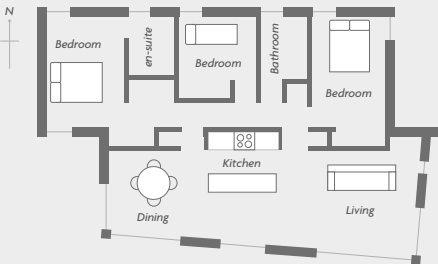


FIGURE 3
SHADING

BUILDING LAYOUT

It is advantageous to employ a compact building shape which focuses on the close grouping of regularly used or 'living' spaces as this can aid the most effective use of passive solar design.

Regularly used rooms should be grouped and aligned with the southern facade of the building, as this allows the most effective use of natural daylighting and solar gain during winter.



THERMAL MASS

In the simplest terms thermal mass describes the ability of a material to store heat energy. In passive solar design terms it is the effectiveness of the thermal mass which is most important.

Effective thermal mass is defined by three key properties; its specific heat capacity, density and thermal conductivity, where;

Specific heat capacity describes the amount of heat energy that 1 kg of a said material can absorb.

Density defines the amount of kilogrammes of a material per unit volume. In thermal mass terms a high density is desirable as more heat energy can be absorbed and stored in each element.

Thermal conductivity describes the rate at which heat energy can flow in and out of a said material. In passive solar design it is desirable that transfer rates reflect the heating and cooling cycle of the building.

Heavyweight construction materials demonstrate these characteristics more effectively than other buildings materials. They typically have high specific heat capacities, by their nature are dense and have moderate thermal conductivity properties (aligning with heating and cooling cycles). The characteristics of a range of materials are shown in Table 1.

TABLE 1

THERMAL PROPERTIES OF COMMON CONSTRUCTION MATERIALS

BUILDING MATERIAL	SPECIFIC HEAT CAPACITY (J/KG.K)	DENSITY (KG/M ³)	THERMAL CONDUCTIVITY (W/M.K)	EFFECTIVE THERMAL MASS
TIMBER	1,600	500	0.13	Low
STEEL	450	7,800	50.0	Low
LIGHTWEIGHT AGGREGATE BLOCK	1,000	1,400	0.57	Medium-High
PRECAST AND IN-SITU CONCRETE	1,000	2,300	1.75	High
BRICK	1,000	1,750	0.77	High
SANDSTONE	1,000	2,300	1.8	High



INSULATION

Heat gain and heat loss is a fundamental consideration for all buildings to ensure occupant comfort. During hot periods it is necessary to stop a buildings heat gain and in cold periods stop its heat loss; effective insulation restricts these heat transfers. Insulation creates a buffer between the internal and external environment and is required to encapsulate a buildings thermal mass for passive solar design to be viable.

VENTILATION

During hot periods a building designed to utilise passive solar principles will aim to minimise solar gains and utilise the fabric of the building to store any heat gains to maintain thermal comfort. Whilst this stored energy will naturally dissipate as temperature balances change with natural day/night cycles this may not be enough to provide capacity within the thermal mass to be effective in the following heating cycle.

In such circumstances a buildings thermal mass may need to be purged of stored heat energy to provide sufficient capacity. This can be achieved through natural ventilation, where stored energy is drawn out of the buildings fabric by lower temperature air passing through the building.

GLAZING

Location, size and type of glazing needs to be considered, along with the influence of building orientation and shading due to its role in daylighting and energy gain and loss. Glazing size should be minimised on north facades to minimise heat loss, whilst on southern facades glazing should be maximised to enable maximum solar gain during the heating season. During the cooling season southern facing windows should be protected for the intensive sun by solar shading.



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UTILISING PASSIVE SOLAR DESIGN

For a passive solar design approach to be successful and effective, its key principles need to be considered in conjunction with each other to create a holistic solution. It's principles are inherently linked and only through the creation of an interdependent system can real benefits be realised.

Passive solar design influences four aspects of a building's operation which has an effect on the comfort of building users. These are heating, cooling, ventilation and daylighting with each achieved through three routes; thermal mass, designing for passive ventilation and natural daylighting. The following table illustrates which of the core principles of passive solar design influence each aspect.

ROUTE TO PASSIVE SOLAR DESIGN	ASPECT	PRINCIPLES
Include thermal mass	Heating and cooling	Orientation, Overshadowing Insulation, Building Layout Thermal Mass, Glazing
Design for passive ventilation	Cooling and ventilation	Orientation, Building Layout
Design for natural daylighting	Daylighting	Orientation, Building Layout, Glazing

INCLUDE THERMAL MASS

Thermal mass describes the ability of a material to store heat energy, which varies with material type (see Table 1). The advantage of heavyweight materials over lightweight materials is not only related to their capacity to store heat energy but the rate at which this energy transfer occurs, in sync with daily temperature cycles. As a result heavyweight materials can assist in regulating temperature demand during both heating and cooling seasons.

SUMMER - COOLING SEASON

By designing and constructing buildings utilising exposed (or easily accessible) heavyweight materials a positive impact on reducing cooling demands can be made. In these circumstances the fabric of the building acts as a heat sink absorbing

incidental heat gain, reducing and stabilising the overall temperature of the building and minimising the risk of overheating. By absorbing heat energy ambient internal temperatures can be maintained at a comfortable level without a significant change in the temperature of the buildings fabric. The ability of the fabric to maintain a lower temperature provides an additional benefit as occupants experience a radiant cooling effect.

Throughout the cooling season during the day windows should be kept closed, preventing the inflow of warm air, which can increase temperatures, with solar shading implemented to minimise solar gain. Successfully implementing these actions will help reduce cooling demands.

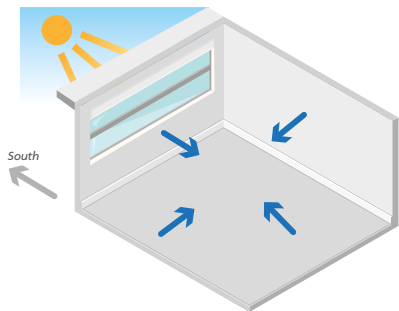
A building's fabric only has a limited capacity to store heat energy, so for continued cooling, over prolonged periods,

it is necessary for the stored heat energy to be removed, resetting capacity prior to subsequent heating cycles. Stored energy in the buildings fabric is purged through night cooling and ventilation. Cooler night

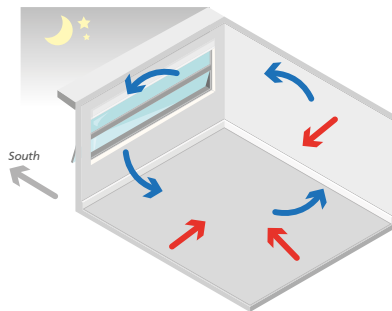
temperatures and air passing through the building serves to draw out stored energy readying the fabric to absorb heat energy during the following cycle.

FIGURE 4
SUMMER COOLING

SUMMER DAY



SUMMER NIGHT



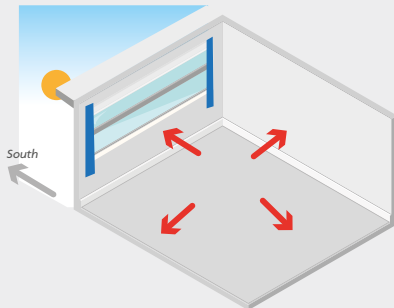
WINTER - HEATING SEASON

Thermal mass of heavyweight construction materials can also provide significant benefits throughout the heating season. It is the ability of the buildings fabric to store energy gains from sources such as people,

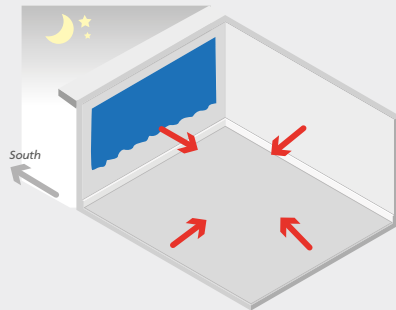
lighting and appliances along with that from south facing glazing which enables these benefits to be realised. As with the utilisation of thermal mass during the cooling season, it is temperature change which draws out stored heat energy.

FIGURE 5
WINTER HEATING

WINTER DAY



WINTER NIGHT



In contrast to the heating season every attempt should be made to avoid the loss of this energy overnight. The slow release of this energy overnight can help to keep the building warm and reduce the demand on energy for heating.

To facilitate this any summer shading on southern facing windows should be designed in a manner so that it only obstructs the high angled summer sun enabling solar gains from the lower angled winter sun. Windows, as a major area for heat loss, should be insulated as best as practically possible overnight by employing curtains or other similar approaches. These enable gains to be maximised and losses minimised aiding the reduction in energy demand for heating.

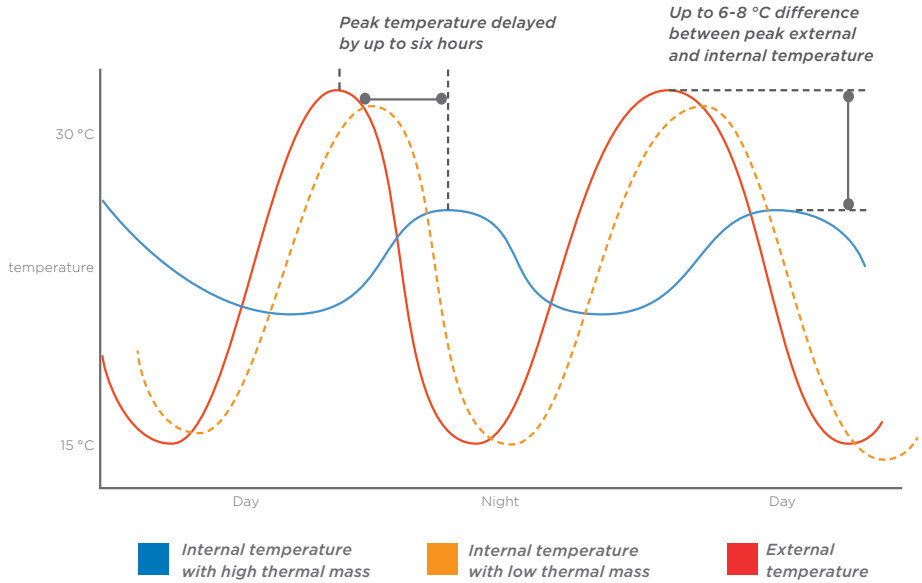
HEAVYWEIGHT OR LIGHTWEIGHT

Whilst the characteristics that define thermal mass are present in all construction materials it is heavyweight materials which exhibit them more effectively for passive solar approaches. Heavyweight

materials, such as concrete, possess a high specific heat capacity, a high density and a moderate thermal conductivity. Heat capacity and density drive the amount of energy that can be stored by the material and thermal conductivity dictates the rate at which this energy is absorbed and released. Heavyweight materials, whilst able to store a lot of energy, also possess a thermal conductivity that aligns to the heating and cooling cycle of building. It is this alignment to the heating and cooling cycle that enables the material to stabilise temperature fluctuations allowing for extremes to be mitigated and occupant comfort to be increased. An example of the positive effect can be seen in Figure 6 relating to summer cooling demands.

Whilst heat capacity, density and thermal conductivity are significant factors in the viability of utilising thermal mass there are also some other key characteristics that facilitate effective passive solar design using thermal mass.

FIGURE 6
COOLING CYCLE⁹



DIURNAL TEMPERATURE VARIATION

Throughout the cooling season the absorption of heat energy by thermal mass is only possible if sufficient capacity exists within the material. Whilst the thermal mass absorbs heat energy during the day it is necessary to purge this stored energy overnight to ensure that it is ready to absorb heat gains the following day. Whilst this can be achieved through a number of methods (such as active cooling) the most sustainable is passive cooling by providing natural ventilation to draw out stored energy. This is only possible if a sufficient diurnal temperature variation exists (difference between peak day and minimum night temperatures) as this drives the flow of heat from the thermal mass to the air.

The UK is well set in this case as the temperature variation is typically around 10° and as such it is feasible to employ night time cooling. It is also possible through the incorporation of active cooling to provide future capacity for increasing global temperatures⁹.

DECREAMENT

This describes the ability of a building element to delay the passage of heat energy from one face to another and its ability to store some of this energy during this process.

Delaying the transfer of heat energy through a construction element can assist in preventing overheating during peak temperatures ensuring occupant comfort. This property is dictated by the same characteristics as thermal mass.

The delay of around 10 to 12 hours with heavyweight materials, results in peak temperatures not reaching in internal spaces until the evening when the risk of overheating has reduced and temperatures are also reducing.

Heavyweight materials have a lower decrement factor, which defines the temperature variation that is experienced within a building based on the diurnal temperature variation.



Heavyweight construction can typically offer a decrement factor as low as 0.1, which based on diurnal temperature variation of 20°C would result in a variation of only 2°C internal temperature variance.

Lightweight construction typically offers a decrement factor of 0.5 which in would result in an internal temperature variance of 10°C for the same diurnal temperature variation⁹.

ADMITTANCE

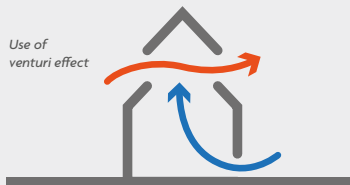
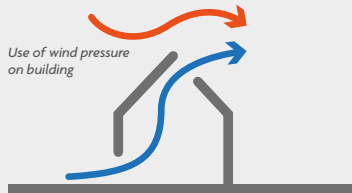
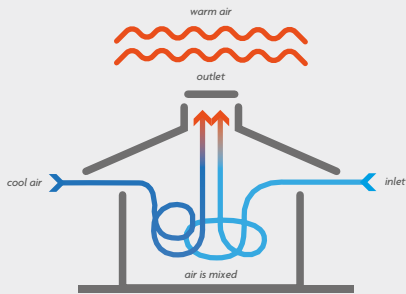
Whilst all of the preceding characteristics have described the thermal mass properties and its ability to perform in maintaining thermal comfort, admittance describes its effectiveness. It is a measure of the ability of an element to transfer heat energy between its surface and the air. Admittance values allow comparisons to be made between construction materials to assess their heat absorption characteristics, those with higher admittance values are more desirable for thermal mass purposes as it allows for faster heat transfer.

PASSIVE VENTILATION

Ventilation is important to provide a source of fresh air to occupants and to maintain air quality but also as a method to maintain thermal comfort. During the cooling season where thermal mass has been employed to moderate internal temperatures any stored energy within the buildings fabric is required to be purged to enable the cooling cycle to continue.

Passive ventilation relies on the design of a building and natural rather than mechanical means to drive air flows. Two approaches exist that can drive passive ventilation, conductive and those that rely on prevailing site winds. Conductive effects are facilitated by the stack effect, where air movement is driven by the rising of warm air.

Thermal stacks in buildings employ high level vents that allow warm air to escape, creating a displacement effect drawing in cooler air at lower levels, ventilating the building. Prevailing wind systems can also be termed as pressure systems, where wind effects on one side of a building creates a pressure differential between the



windward side and the leeward side. This pressure differential drives external air into the building and forces internal air out, a common approach is cross ventilation and relies on the organisation of the building layout to reflect this approach.

DAYLIGHTING

Passive solar design facilitates daylighting by encouraging building design to make use of solar gains. Building orientation towards the south, use of glazing and intelligent layouts, enables natural light to be captured throughout the day in the most used spaces. Concrete offers further opportunities due to its naturally low albedo and ability to be coloured to increase reflectivity.

At Tarmac, safety and sustainability is at the forefront of everything we do.

Our vision is “to be our customers’ preferred choice for sustainable construction solutions”. We are focused on building long term relationships with our customers helping them to consider and think about the social, environmental and economic effects of what we do not just for now but for the future.

To enable this we need to follow a holistic approach considering construction solutions rather than construction materials alone.

The products that we supply perform significant roles in the delivery of sustainable construction solutions of which passive solar design is one. Concrete as a heavyweight construction material, through its thermal mass credentials plays a key function in enabling passive solar design, whilst its resistant and durable qualities facilitate longevity of design.

It is the versatility of concrete that allows the material to perform dual roles in buildings, acting as structural load bearing elements whilst providing architectural final finishes. Concrete can provide high quality flat finishes or take on almost any form or shape, facilitating architectural flexibility. In passive solar design terms direct access to thermal mass is favourable, as additional finishes can act as a barrier reducing effectiveness and efficiency of heat energy transfer.

The architectural flexibility of concrete reduces the need for additional finishing materials providing direct access to thermal mass.

Concrete has a high specific heat capacity, a high density and a thermal conductivity that allows it to synchronise with the daily heating and cooling cycles experienced in the UK. It is also possible through material design to adjust its constituents to develop a material whose thermal mass affecting characteristics have been fine tuned. This allows the development and specification of a material which will be able to react to the demands of the environment in which it is employed.

The naturally high albedo of concrete can facilitate the deeper penetration of natural daylight into buildings. Material colour can be changed and along with different finishing techniques, such as polishing, to enable albedo and daylighting properties to be improved⁶.

The credentials of our products enable them to be implemented as construction solutions. These are demonstrated through our Solution Guides which aim to help deliver not only passive solar strategies

but additional systems which contribute to the sustainable delivery and operation of buildings.

We define a sustainable building as a building which has, through its design, considered its effect on economy, the environment and society. In response to this it has been designed to mitigate and minimise these effects at every stage through its life. Our Solution Guides introduce and detail solutions that can help achieve this.

These systems are not solely linked to passive solar design but also provide further wide reaching sustainability benefits, with more details available on our website (www.tarmac.com).

Our Vaulted Ceilings and Decorative Concrete (Interior) Solutions Guides exemplify the positive effect that passive solar design and the utilisation of concrete's inherent thermal mass can have on improving thermal comfort and reducing heating and cooling energy demand.



SUSTAINABILITY

There are a number of sustainability assessment schemes that exist which are used to measure the sustainable credentials of the built environment, such as BREEAM, LEED and CEEQUAL.

Whilst schemes exist such as Passivhaus which are highly influenced by passive solar design, there are no direct schemes to measure the passive solar performance. Schemes such as BREEAM and LEED are focused on providing a holistic view of a buildings sustainability credentials. Whilst passive solar design is not directly measured, credits can be gained through its implementation.

More details on the role that construction materials can play in the achievement and award of credits as part of the BREEAM scheme can be found in our accompanying guide to BREEAM for construction materials.



SUSTAINABILITY ASSESSMENT SCHEMES

The Building Research Establishment Environmental Assessment Method (BREEAM)¹¹ is the most applicable environmental benchmarking scheme for the UK construction market. The scheme is also recognised and implemented internationally. Whilst there is no direct reference to the implementation of passive solar methodologies there are a number of issues and criteria which can be satisfied by its inclusion.

BREEAM assesses sustainability performance over ten distinct categories and within each category there are a number of specific issues that are used to measure sustainable performance. These categories are;

MANAGEMENT

Focused on management policies and the procedures that need to be put in place to ensure the delivery of a sustainable project.

HEALTH AND WELLBEING

Concerned with internal and external issues that can affect the health and wellbeing of the building occupants.

ENERGY

Describes the requirement for the measurement of the operational energy of the completed project. It includes steps taken to reduce its impact, such as the introduction of low or zero carbon technologies.

TRANSPORT

How well the development links into public transport networks and encourages the use of sustainable transport systems.

WATER

Encourage the responsible use of water resources with the implementation of water efficient equipment and monitoring to actively reduce water consumption.

MATERIALS

Primarily concentrated on the life cycle impacts of the materials used within construction and the assurance of responsible sourcing.

WASTE

Promotion of schemes to encourage the reduction of waste throughout the construction phase and the avoidance of waste to landfill during operational life.

LAND USE AND ECOLOGY

Encourage the selection and use of sites that minimise effects on existing ecology and avoids the use of virgin land.

POLLUTION

Concerned with the reduction and elimination of all forms of pollution, be it surface, atmospheric, light or noise.

INNOVATION

Opportunity for additional credits to be awarded as a result of sustainability benefits that are related to the project but are not rewarded in standard BREEAM issues.

The issues where passive solar design can play a role in obtaining BREEAM credits are as follows;

Health and Wellbeing 01 - Visual comfort

To ensure daylighting, artificial lighting and occupant controls are considered at the design stage to ensure best practice in visual performance and comfort for building occupants. Up to two credits are available where good levels of natural daylighting is provided which is encouraged through passive approaches.

Health and Wellbeing 02 - Indoor air quality

To recognise and encourage a healthy internal environment through the specification and installation of appropriate ventilation, equipment and finishes. One credit is available for the implementation of natural ventilation, an approach that can be achieved and made viable through passive solar methods.

Health and Wellbeing 03 - Thermal comfort

To ensure that appropriate thermal comfort levels are achieved through design, and controls are selected to maintain a thermally comfortable environment for occupants within the building. Thermal comfort is a key tenant of passive solar design, whilst its implementation enables a reduction in heating and cooling energy demand this is only facilitated through the ability to maintain comfort levels for occupants. This ability to provide comfort enables passive solar design to contribute to the achievement of 2 credits.

Energy 01 - Reduction of energy use and carbon emissions

To recognise and encourage buildings designed to minimise operational energy demand, consumption and CO₂ emissions. Passive solar design enables the energy demand for heating and cooling to be reduced through the utilisation of the fabric of the building and the energy provided through solar gain, occupants lighting and appliances. Through this issue up to 15 credits can be awarded.

Energy 04 - Low carbon design

To reduce carbon emissions and atmospheric pollution by encouraging local energy generation from renewable sources to supply a significant proportion of the energy demand. Within this issue free cooling has great relevance to passive solar design as natural ventilation can be implemented through successful implementation. The use of natural ventilation and free cooling strategies allows for the awarding of 1 credit.

Pollution 02 - NOx emissions

To encourage the supply of heat and/or coolth from a system that minimises NOx emissions, and therefore reduces pollution of the local environment. Creation of these emissions tends to be a result of the plant that is required to be used for mechanical ventilation, air conditioning and heating. By following and utilising passive measures the demand for heating and cooling can be reduced, minimising plant and equipment, therefore reducing potential NOx emissions. The number of credits that can be achieved and influenced through this issue is dependent on building type.

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.

The construction products and solutions that we at Tarmac supply play an important role in the realisation of the benefits of passive solar design due to their inherent characteristics.

Following passive solar design principles creates the opportunity for significant sustainability savings and improvements to be achieved in terms of reducing energy demand for heating and cooling to provide thermal comfort for occupants.

For more information on how to implement passive solar design principles within your project contact **sustainability@tarmac.com**

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