TECHNICAL PAPER

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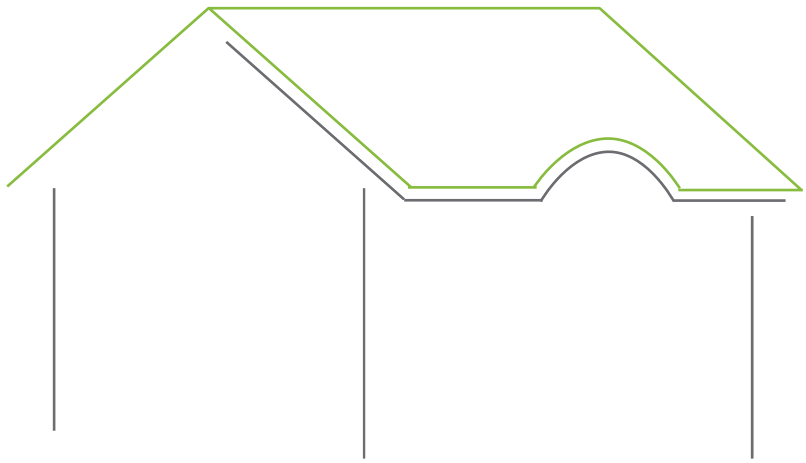
Metal Roofing for Comfortable, Energy-Efficient Housing



ecca

prepaintedmetal.eu

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Introduction

Around Europe, there are many different styles of housing in common use, with the design of buildings being a product of history and tradition. However, one issue which is bringing Europe closer together than ever is the need to reduce our dependence on fossil fuels and their effect on climate change. Since energy used in buildings accounts for the largest single use of energy in Europe, we need to take a critical approach to building design for the future.

The use of metal roofing has a long tradition in some parts of Europe, but across most of Europe, it is not as popular as the various forms of tile roofing, whether they be made from clay, stone, slate or, more recently, concrete. The choice of roof covering can be made on purely aesthetic grounds, but it is important to understand the effect that this choice may have on the thermal comfort and energy efficiency of the dwelling.

ECCA, in partnership with the Oxford Institute for Sustainable Development (OISD) at Oxford Brookes University in the UK have undertaken a major study to understand the effect of roofing choice on the thermal comfort and energy efficiency of dwellings in Europe. This study focuses on a bedroom in the upper floor of a house with a warm roof construction. While this may not be typical of all domestic situations, it was chosen to provide the greatest effect of the roofing material on the thermal parameters inside the house.

Photo courtesy of ArcelorMittal

Photo courtesy of Ruukki

Photo courtesy of Didier Hardy

The OISD Study

The architectural typology of buildings around Europe varies greatly. Likewise, the relevant legislation regulating construction methods varies from country to country and sometimes even within a single country. However, following a survey of typical building methods in several countries, the OISD study concluded that a simple model could provide reliable information which would be applicable across a very broad spectrum.

The OISD study centred around a computer simulation using IES TAS software linked to accurate representative weather data. A virtual building was constructed within the modelling software to represent a semi-detached dwelling of masonry construction with a habitable space in the roof area and a roof slope of 40°.

Once the model was prepared for each location, with relevant insulation values, a typical annual weather pattern was applied for that location. The outputs of the modelling software included internal and external temperature and energy usage in heating and/or cooling to maintain a given temperature range.

The full OISD study can be found on the ecca website at

www.prepaintedmetal.eu.

Three important variables were considered in this study:

Insulation

The largest effect on energy usage and thermal comfort is from insulation in walls and roof. All modelling was carried out using standard levels of insulation as determined by local building control regulations.

Thermal mass

The major difference between a metal and tile roof in terms of thermal behaviour is the thermal mass of the two options. Thermal mass is the ability of a material to absorb and retain heat. Clay, concrete or stone tiles have relatively high thermal mass, while metal has relatively low thermal mass.

Solar reflectivity.

It is widely known that light surfaces reflect more heat than dark ones. With a coated metal roof, it is possible to tailor the heat reflective properties by applying a different colour, or even by changing the pigmentation without drastically changing the colour. To assess this affect, the study modelled a coated metal roof with two different levels of reflectivity – one the same as for clay tiles and one significantly more reflective.

Since the major differences between a metal and tile roof (thermal mass and reflectivity) involve their reaction to heat, modelling has been restricted to Southern Europe where the effects of such differences will be the greatest. Since average external temperatures and solar irradiation are less for regions further North, and also since higher levels of insulation tend to be used in more Northerly regions, any effects observed will be less significant in the North of Europe.

The Effect of Insulation

Thermal insulation is the best means of minimising the energy required to maintain a comfortable environment inside a building whatever the weather outside. For this reason, the European Energy Performance of Buildings Directive (EPBD) requires all European Member States to adopt a mandatory level of insulation in all new buildings. Moreover, a key requirement of the EPBD is that when major renovation (such as re-roofing) is carried out, insulation must be improved up to an equivalent level as for new-build.

Whether it is for a new-build or a new roof on an old building, all roofs installed in Europe must include a level of insulation. The amount of insulation required varies depending on climatic conditions, so for example Finland has a maximum allowable U-value of 0.16 W/m²K, while in Southern Italy, the maximum allowable U-value is 0.60 W/m²K.

Insulation used in a rooaf isolates the inside from the outside very effectively so that any effect of the roof covering, for example on external temperature, is almost negated by the insulation. For example, Figure 1 shows the temperature of the internal and external surfaces of a roof with either clay tiles or a high-reflectivity metal roof in Strasbourg, France, with a U-value of 0.20 W/m²K, taken over a typical summer week. In this case, while the external temperature of the two can differ by up to 20°C, the temperature difference inside the property is never more than 2°C.

With most of Northern and Central Europe adopting an insulation level of at least 0.35 W/m²K, and many with requirements much more stringent than this, the choice of roof covering on the thermal comfort inside the building in these cases is negligible. However, as can be seen in the figure, choice of roofing may impact significantly on the external temperature of the building which can affect the urban heat island effect, as discussed later.

Many parts of Southern Europe, with mild winters, have much lower requirements for thermal insulation, so more potential for the roofing material to affect the thermal comfort of the interior of the building. Importantly, these areas also tend to have hotter summers and a greater potential for overheating in buildings.

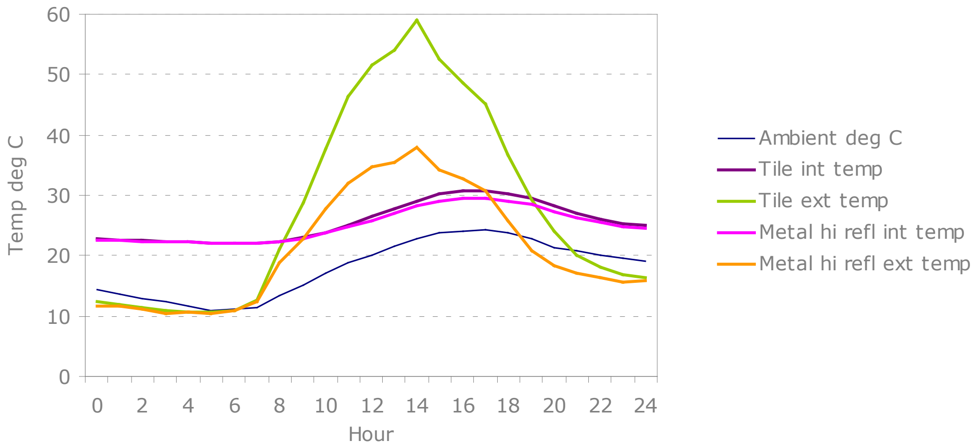


Figure 1

Strasbourg upper bedroom, summer day

Temperature of a clay tile and metal roof in Strasbourg with a U-value of 0.20 W/m²K during a summer day

The Effect of Thermal Mass

A tiled roof has significantly greater thermal mass than a metal roof. During the day, the tiled roof will absorb heat which it will re-emit gradually during the night when the air temperature is lower. A metal roof responds much more quickly to temperature variations since it does not absorb nearly as much heat.

To emphasize the effect of thermal mass, the OISD study assessed two locations in Southern Europe, Naples (Italy, with a U-value of 0.55 W/m²K) and Athens (Greece, with a U-value of 0.50 W/m²K). In both cases, when assessing the internal temperature over the course of a summer day, it could be seen that the building with a metal roof heats up and cools down quicker than that with a tile roof (see Figure 2).

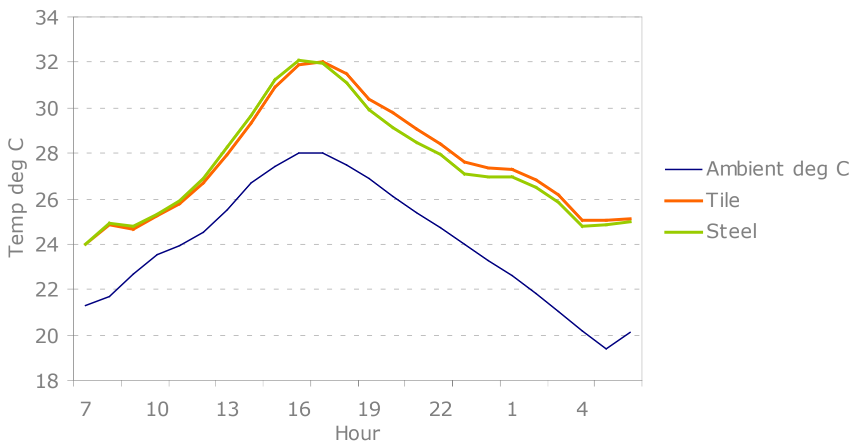
In some cases, on the hottest of days, the peak temperature inside the building with the tile roof is marginally lower than inside the building with the metal roof. In this case, the thermal mass of the tile roof has had a positive effect in reducing the height of this peak. However, this effect is very much limited, since as the day progresses, equilibrium between the two roofs is soon reached and as the tile roof cools more slowly, the metal roof provides a lower internal temperature for much of the day.

Taking the full cycle of day-night, overall the building with the metal roof is marginally cooler than that with the tile roof. For the example shown in Figure 3, modelled in Athens, it can be seen that, while the building with the metal roof may spend marginally more time at temperatures over 38°C, for temperatures below 30°C the building with the metal roof performs better. The net effect is that the building with the metal roof spends less time at elevated temperature than that with the thermally massive tile roof.

Figure 2

Naples upper bedroom, summer day

Showing the temperature inside an upper-storey bedroom in Naples through a summer day and showing the time-lag effect of thermal mass for a tile roof



When assessing thermal comfort and the necessity of cooling, it is important to understand the usage pattern of a building. In the case modelled, the upper-floor room is assumed to be used as a bedroom. In the majority of European cultures, this would be the normal case. The thermal requirements of a bedroom are most stringent during the late evening and night time.

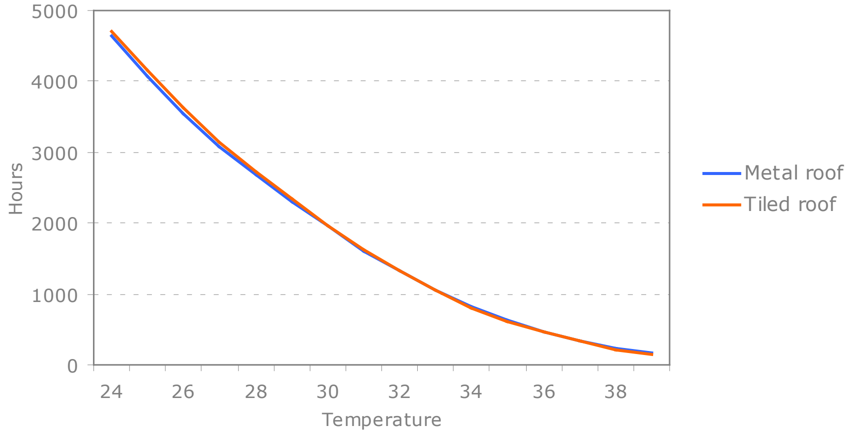


Figure 3

Athens temperature excess hours comparison

Hours-over-temperature graph for an upperstorey bedroom in Athens

Assessing the same case of a building in Athens, but now only looking at the temperature during night time (between 22:00 and 08:00) when the bedroom is likely to be in use, we can see that the difference between a thermally massive tile roof and a thermally responsive metal roof is much more significant, as shown in Figure 4. For example, with a tile roof, the bedroom could spend 13% more night-time hours above 27°C than with a metal roof.

If cooling is used to reduce the bedroom temperature to a comfortable temperature of no more than 24°C, the OISD study shows that in this modelled house in Athens, over 11% more cooling energy is required for a house with a tile roof than for one with a metal roof. Repeating this study in Naples, where thermal insulation is slightly less, but the summer sun is slightly less fierce, the saving in cooling energy is around 9% by using a metal roof in place of a tile one.

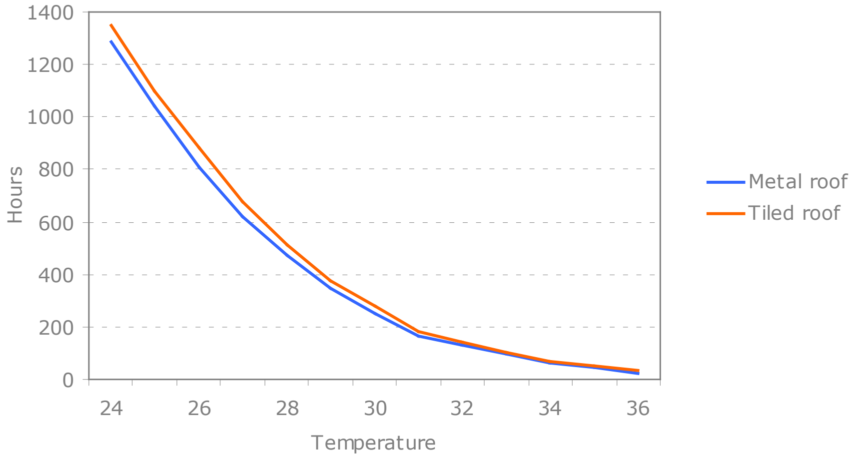


Figure 4

Athens night time temperature excess hours comparison

Hours-over-temperature graph for the upper-storey bedroom in Athens, looking only at night-time hours

The Effect of Solar Reflectivity

Solar reflectivity is a property which is often ignored, but can be very important in determining the thermal behaviour of a surface. In a roof, a solar reflective roof covering will maintain a much lower exterior surface temperature than a thermally absorbing roof. This means that less heat is transmitted to the inside of the building and there can also be benefits to the surrounding environment.

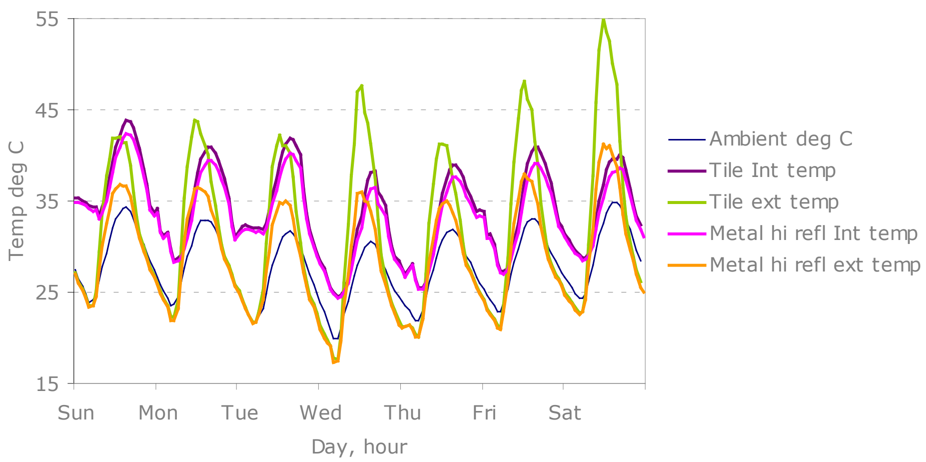
With a coated metal roof, the solar reflectivity can be chosen, either by choosing the colour of the roof or by modifying the pigmentation for a given colour, to meet the requirements of the location. So, in Southern Europe, a roof with high solar reflectivity can be used, while for a similar building in Northern Europe, where heat loss is more of an issue, a low solar reflectivity can be specified in essentially the same material.

By running the model in the OISD study with both solar reflective and absorptive metal roofs, the effect can be observed. Taking again the example in Athens, it is clear to see from Figure 5 that the peak external temperature of the high-reflectivity metal roof can be up to 20°C lower than that of a tile roof on a summer's day. This translates into a noticeably lower internal peak temperature on each day within the summer.

Figure 5

Athens upper bedroom, summer week

External and internal surface temperatures for a tile roof and a heat-reflective metal roof through a summer week in Athens



Unlike the peak-lopping effect of thermal mass, the high-reflectivity roof maintains a lower internal temperature throughout the entire summer day. Since the reflectivity is only an issue during day-time, the highly reflective metal roof behaves just like the normal metal roof during night-time, again giving the benefit of thermal responsiveness.

The effect of the high-reflectivity metal roof is limited to the day-time, so in the case discussed earlier of night-time cooling for a bedroom it makes very little difference. However, if the room were used in the day, for example for an office, then the reflective metal roof would provide a much more comfortable environment and significantly lower cooling requirements. Figure 6 shows the hours over temperature, again in Athens, taking into account the full daily cycle. Here we can see that the highly reflective metal roof is always cooler than the tile roof. For example, the tile roof produces an internal temperature over 32°C for 22% more hours than the reflective metal roof.

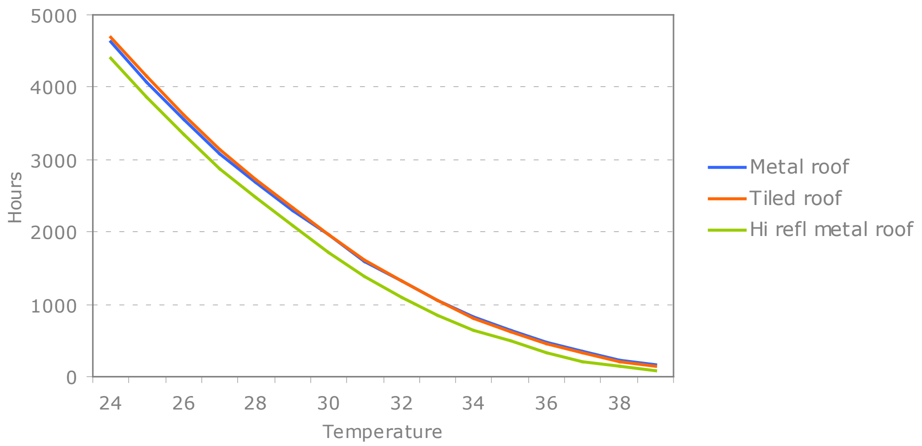


Figure 6

Athens temperature excess hours comparison

Hours-over-temperature graph for an upper-storey room in Athens, showing how much cooler the room is with a solar-reflective metal roof

The Urban Heat Island Effect

In 2006, 49 % of the global population (equivalent to 3.2 billion people) lived in cities while only 13% of the population did in 1900. By 2030, it is estimated that nearly 5 billion people will live in urban areas. This level of urbanisation brings with it many environmental challenges, one of which is the urban heat island (UHI) effect.

The principle cause of urban heat islands is the storage by day of solar energy in the urban fabric and release of this energy into the atmosphere at night. The air temperatures in cities can be several degrees higher than that of the surrounding countryside and this effect is particularly noticeable at night. During warm summer spells, cities see increasingly elevated temperatures as insufficient nighttime cooling takes place to balance the daytime heating and this effect is only made worse by increasing use of air conditioning that generates further heat.

Photo courtesy of Corus

The urban heat island effect has been measured in cities around the world and is not confined to those in hotter climates. In temperate areas such as London and Paris, the UHI effect has been blamed for deaths from overheating in recent summers.

In an attempt to minimise the UHI effect city planners are increasing green space within cities, but another practical measure that could be taken is to minimise the amount of heat absorbed by thermally massive roofing.

The OISD study showed that the maximum temperature of a reflective metal roof on a summer day could be over 20°C lower than a thermally massive tile roof, while the average summer daily temperature of the roof was predicted to be nearly 9°C lower.

The thermally responsive nature of metal roofs means that they do not hold heat into the night – the main cause of the UHI effect – and they can play a part in minimising the urban heat island, particularly when coated with a highly reflective coating.

Besides helping to combat the urban heat island effect, metal roofs can also help to minimise the harmful effects of global warming. It is commonly accepted that the Earth is warming up due to the so-called "Greenhouse effect". Gasses in the atmosphere (mostly CO_2) are trapping heat and it is important to understand the mechanism of the greenhouse effect since not all heat is trapped.

The atmosphere is thermally transparent to certain wavelengths of radiation, which is how heat from the sun arrives on the surface of the Earth. If this heat is reflected directly back, then it does not cause warming of the atmosphere. However, if this heat is absorbed, e.g. by thermally massive tile roofing, then when it is released, it is re-emitted at a different wavelength which is trapped by CO_2 in the atmosphere. This is the principle behind the greenhouse effect, which is causing global warming.

Conclusions

The OISD study for ECCA has shown that the choice of a metal roof for a residential building can have significant advantages, although this depends on the specific location of the building.

The use of insulation in roofs tends to isolate the inside of a building from the outside so that where high levels of insulation are used, the choice of roof covering has little effect on the thermal behaviour inside a building. However, where less insulation is used, mostly in warmer parts of Europe, a metal roof can provide a more comfortable internal environment than a tile roof.

In Southern Europe, metal roofs provide better night-time comfort in upper-storey bedrooms than tile roofs and where air conditioning is used, this can reduce energy usage by up to 11%.

Where internal day-time temperature is important, highly-reflective metal roofs can significantly improve thermal comfort in Southern Europe, with tile roofs giving over 20% more hours over an internal temperature of 32°C than reflective metal roofs.

Beyond the direct effect on internal comfort, metal roofs, particularly when coated with a solar reflective coating, can help to minimise the urban heat island effect and can play their part in minimising the greenhouse effect which is behind global warming.

Photo courtesy of Corus

Photo courtesy of ThyssenKrupp Steel

Photo courtesy of BASF

ECCA MISSION STATEMENT

ECCA is dedicated to the promotion of the use of coil and/or sheet coated metal as the environmentally sound, the cost effective and the high quality method of finishing.

ECCA OBJECTIVES

Setting quality performance standards and developing test methods

Promoting the benefits of coil and/or sheet coated metal with particular emphasis on environmental, cost and quality benefits.

Stimulating product, process, application and market development

Increasing the awareness of coil and/or sheet-coated metal through professional marketing and by organising educational training programmes for non-users

Creating an industry network and forum for the development and exchange of ideas

Representation of the Industry in its contacts with Public Officials and Public Authorities

Providing liaison with other Trade Associations and Professional Bodies.

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