Cool metal roofing in Europe

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ABSTRACT

The use of cool metal roofing has grown extensively in some parts of the world in the past 10 years, particularly in the USA where various local and national legislation and schemes explicitly support the technology. However, the use of this technology in Europe is still very limited. There are three main factors which influence the adoption of cool metal roofing across Europe, being: climatological inhomogeneity; building practices and insulation; and building typology and usage patterns. Each of these factors will be explored in some detail, drawing a virtual map of the applicability of cool metal roofing across Europe. It is found that the benefits of cool metal roofing are two-fold, being a thermal comfort issue in certain building types and certain locations, but also a much more widespread benefit in helping to tackle the issue of urban heat islands. By mapping out the applicability of the technology in this way, we can establish the most likely scenarios for significant growth in the use of cool metal roofing in Europe to parallel that in other parts of the world.

1. INTRODUCING COOL METAL ROOFING

1.1. Metal Roofing

There is a long history in many parts of the world of using profiled metal as the external skin of roofing for many different types of buildings. Since architecture is a product of local history, around Europe there is a great diversity in building form and the use of metal roofing has traditionally been locally focused. For example, in France, standing seam roofing is widely used in cities such as Paris, while many houses in the mountainous regions also have metal roofs, but for housing in other regions clay tiles are more popular.

The origins of metal roofing, in many regions at least, in rural and agricultural buildings has developed into modern use in many industrial and warehouse buildings, which again has led onto use in many commercial buildings. In many cases, where large roof areas require a highly durable and weathertight roof, metal roofing is the obvious choice and so this usage pattern now leads to a very diverse range of metal roofed buildings. Meanwhile, the varied aesthetics offered by metal roofing, together with it's light weight, low maintenance requirement and ease of fitting mean that this is increasingly used in smaller buildings as well as the larger applications.

The majority of modern metal roofing uses prepainted metal. The metallic substrate is usually either steel or aluminium, although zinc, both bare and increasingly in a prepainted form, is also widely used. Prepainted metal has a paint coating applied under very tightly controlled factory conditions, so the coatings applied are of a high quality and can last for extended periods. Indeed, many prepainted metal products for roofing are now available with guarantees offered by the manufacturer for up to 40 years. Modern prepainted metal for roofing will maintain it's colour and gloss for many years and will provide a high level of corrosion resistance to the underlying substrate. If applied correctly and regularly washed by rain-water, prepainted metal roofs frequently need no maintenance for 30 years or longer and with attention to the ends of metal sheets and potentially eventual over-painting, the metallic substrate will be protected to give assured weatherproofing indefinitely.

For roofing, prepainted metal is used in three different forms:

- Corrugated roofing
- Standing seam roofing
- 3D-profile roofing

The fact that metal roofing is prepainted allows the building owner to choose from a wide palette of colour and gloss combinations to provide almost any desired aesthetic. Many larger buildings use grey-coloured roofing, being purely functional, but even for large roofs, there can often be certain visual requirements, particularly where the building can be overlooked. For smaller buildings, or those in an urban setting, the roof is more often visible and here, the choice of colour and gloss can be very important. In some locations, a very high gloss can be desirable, while in others, a matt finish is much preferred. Prepainted metal can use a range of greys and silvers to display the materiality, or can be used in different colours, either to mimic other roofing materials, to fit into a local aesthetic, or to stand out. Particularly when used on aluminium, clear-coats, which protect the metal substrate but maintain the original aesthetic, or tinted coatings can be used to provide interesting effects.

1.2. The Application Of Cool Roofing To Metal Roofs

As discussed above, the majority of modern metal roofing uses prepainted metal and so the coating can be tailored to maximize the cool properties. Uncoated metal suffers from very low emittance, so most heat which is absorbed is retained, leading to very hot surfaces, but the surface of prepainted metal has a high emittance. The coatings used can give any colour and using modern pigment technology, can even give high IR reflectance with a choice of colours.

To achieve a cool metal roof, there are two options available:

- Use a light colour, or even white; or
- Use a specially developed colour which is highly reflective in the IR region.

The additional cost of using very light or white coloured roofing is very often zero, since most basic colours of prepainted metal are available at no additional cost. However, in many cases, a white or very light coloured roof is not acceptable. In these cases, a specially formulated cool colour can be used at only a very minimal cost increase to the overall roof cost.

Because of the nature of metal roofing, it can be used on both new build and refurbishment. For most new-build projects, a metal roof could be used, giving a very economical approach to delivering a cool roof. In major refurbishment projects where the existing roof covering is to be replaced or covered over, a cool metal roof is also an ideal option, since the light weight (compared to most other roofing systems) means that virtually any roof structure can support a metal roof and particularly where the existing roof is to be covered over (for example to encapsulate an asbestos roof) then the light weight of a cool metal roof is a critical factor.

Some of the key advantages of cool metal roofing can be summarized as:

- Available at little or no cost differential
- Available in standard established roofing systems
- A wide range of colour and heat reflection properties available
- Painted surface gives high emissivity
- Low thermal mass

- Reflective properties retained better than other technologies
- Cool metal roofing can reduce thermal expansion

The aged performance of cool roofing is a critical factor which is included in assessment of cool roofing materials within various schemes in USA. Studies have shown that light coloured prepainted metal typically loses less than 10% of it's initial reflectivity over a period of three years, in contrast to either post-applied coatings or white single-ply membranes which loose reflectivity much quicker. Additionally, the prepainted metal surface maintains a relatively constant reflectivity beyond this 3 year period, again unlike other materials. Furthermore, prepainted metal products are now available with increased dirt-shedding properties to reduce even further any effect of dirt build-up.

2. COOL METAL ROOFING IN EUROPE

Although widely used elsewhere and particularly in North America, cool metal roofing has not yet seen widespread use in Europe. The purpose of the study reported in this paper is to understand the applicability of cool metal roofing in Europe, with particular reference to specific building types and their usage patterns.

To assess the applicability of cool metal roofing, we have developed a model which, on the one hand looks at the benefits which cool metal roofing can bring and on the other the factors affecting it's performance. The benefits of cool roofing, in this respect, can be summarized as:

- Increase in thermal comfort
- Decrease in cooling costs
- Mitigation of the urban heat island effect

The first two of these are closely aligned, since they both depend on the effect of the roof on the internal climate of the building, while the third looks at the external climate. For this reason, the urban heat island effect is considered separately in section 3.

The factors affecting the performance of a cool metal roof for a specific building can be summarized as:

- Heat radiation intensity
- Ambient external temperature
- Extent of insulation
- Internal requirements of the building

The first three of these factors are determined essentially by geographical position of the building, while the third is a function of building typology and use.

2.1. The Effect Of Insulation

Cool metal roofing is most likely to be applied either in new-build projects or in major refurbishment which involves replacement or encapsulation of the whole roof. Under the European Energy Performance of Buildings Directive (EPBD) there are minimum insulation requirements in all new-build properties, while all major refurbishments are required to include an element of upgrading the energy efficiency of the existing building. For this reason, it can be assumed that all cool metal roofing in Europe (with some exceptions, as discussed later) is to be installed on insulated roof systems.

In much of Europe, and particularly in the North, the major use of energy in buildings is for heating. For this reason, building regulations around Europe have evolved to stipulate a minimum insulation level and this is supported by the EPBD. Surveying the minimum required insulation levels across the European Member States shows that there is a clear trend towards higher levels of insulation being used in Northern-most countries, with a lower annual average temperature. Figure 1. shows a plot of required maximum U-value for various countries, with the order of countries being determined by their annual average temperature (from cold to hot).

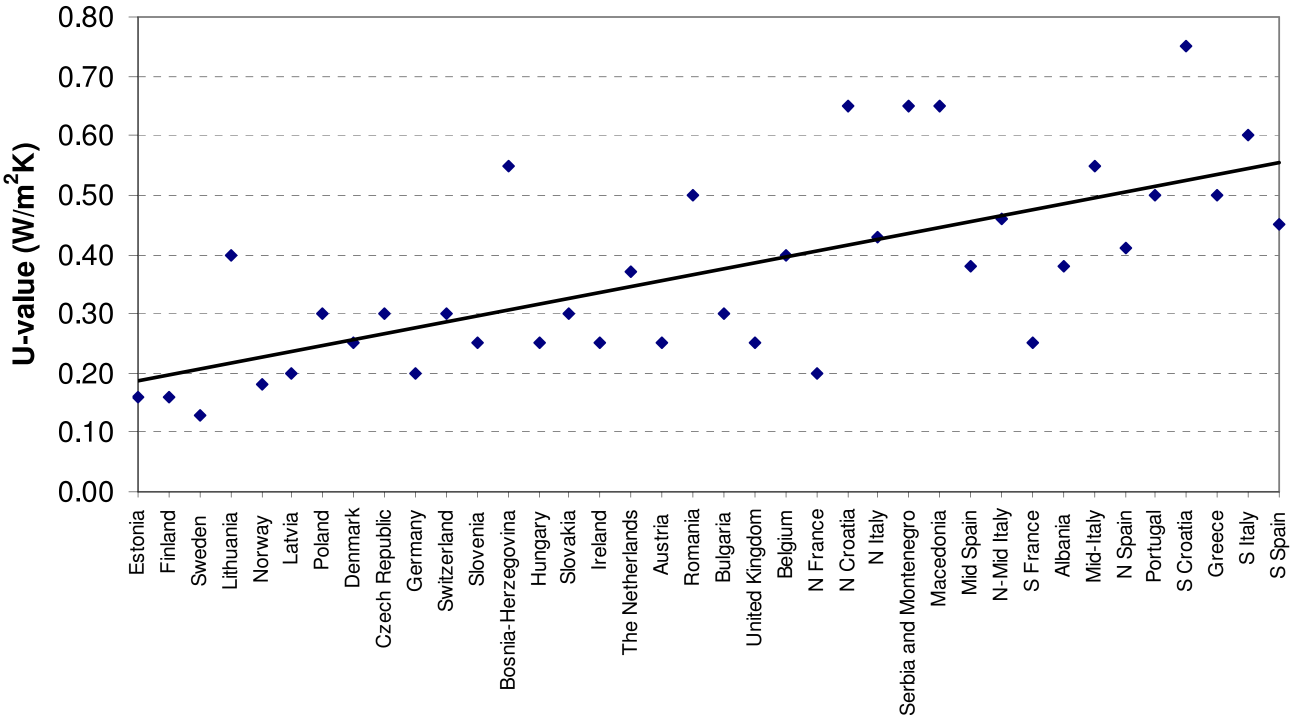


Figure 1. Required maximum U-value in European countries, ordered from cold to hot based on annual average temperatures

It can be seen that, with very few exceptions, countries and regions up to and including Northern France have maximum permitted U-Values no higher than 0.40 W/m^{2}K and very often much lower, while those countries and regions which are hotter than Northern France (again with only very few exceptions) have required maximum U-Values greater than 0.40 W/m^{2}K.

The effect of insulation is to isolate the interior climate from the exterior and the extent of insulation determines the effectiveness of this isolation. In order to demonstrate this, we have produced a model of a conventional house within IES thermal modeling software and varied the roof covering. This modeling has been carried out using several different European weather data-sets and corresponding insulation levels in each case.

When the model is run for Strasbourg, France, with a roof insulation U-value of 0.20 W/m^{2}K (as required by local regulations) a dramatic difference can be seen between the exterior temperature of the roof when using either a conventional tile roof (solar reflectivity 30%) or a highly-reflective metal roof (solar reflectivity 70%). However, when assessing the internal temperature of an upper-storey room, there is very little difference in peak temperature and throughout much of the day, there is no difference in internal temperature. Figure 2. shows the internal and external temperatures of the simulated conventional tile and cool metal roof buildings over a typically sunny day in July, demonstrating the isolation of the interior from the exterior when using insulation with a U-value of 0.20 W/m^{2}K.

In contrast, when the same simulation is done for the same building, but in Athens, with a U-value of 0.50 W/m^2K (as required by local regulations) then, while the difference in maximum external temperature is similar, there is a much more significant difference in internal temperature. Results from Athens are shown in Figure 3.

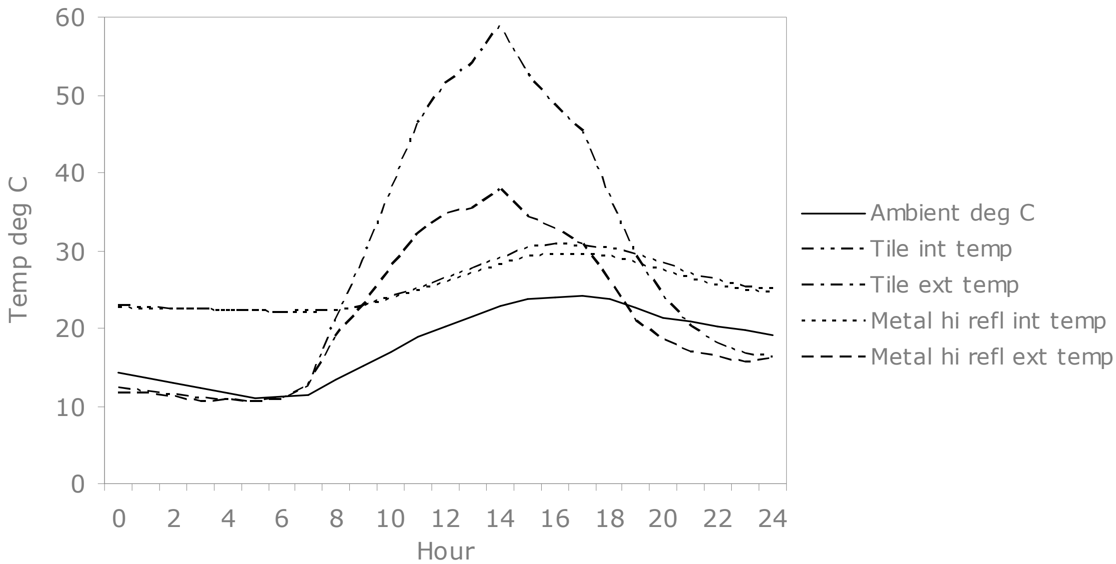


Figure 2. Temperature of the exterior and interior roof surface modelled on a standard house in Strasbourg over a typical sunny July day with either low-reflectivity tile or high-reflectivity metal roofing, showing how little variation there is in the internal temperature compared to the external temperature

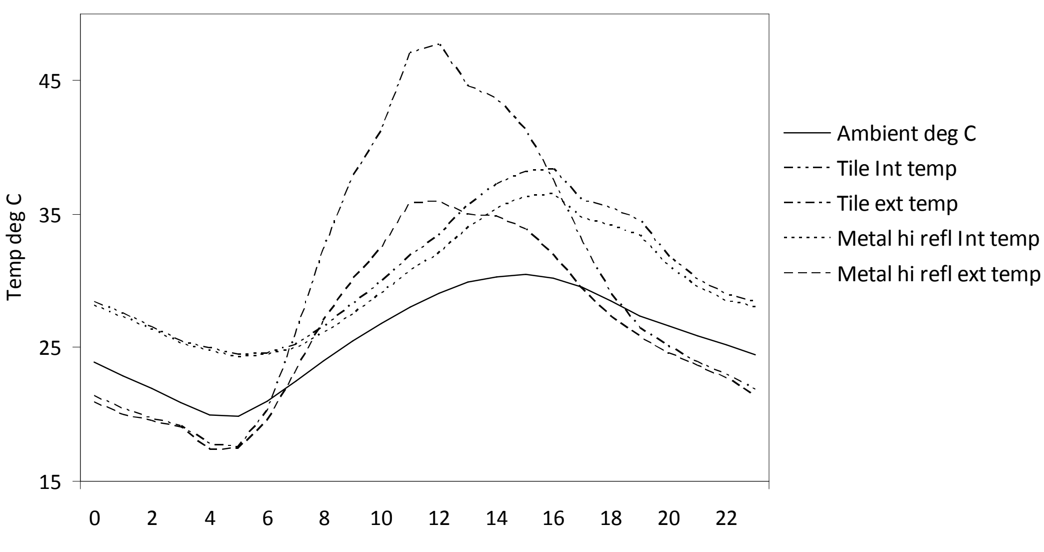


Figure 3. Temperature of the exterior and interior roof surface modelled on a standard house in Athens over a typical sunny July day with either low-reflectivity tile or high-reflectivity metal roofing

In conclusion on insulation, it can be clearly seen that, where insulation is used, the effect of a cool roof is significantly reduced due to isolation of the internal environment from the external one. However, in many areas of Southern Europe, where insulation requirements are less, then cool roofing can have an impact on the internal temperature of buildings, and so on thermal comfort and potentially on cooling costs.

2.2. The Effect Of Building Type And Use

We have shown that, in certain cases where lower levels of insulation are used, cool metal roofing can lead to reduced internal temperatures. However, to further quantify the benefits, it is important to consider the thermal requirements of specific building types. For this purpose, we will investigate four typical building types, namely:

- Residential
- Office
- Warehouse or factory
- Animal housing

2.2.1. Residential

Residential buildings can be classified as houses or apartments and the former can further be classified as detached, semi-detached or terraced and also as single-storey or multi-storey. However, for the benefit of the current study, it is important only to investigate the rooms closest to the roof. For most residential buildings throughout Europe, the upper storey is generally used as sleeping accommodation, with living accommodation being on a lower storey. In the case of apartments, this is not necessarily true, although it is important to consider that only the top-most apartment will be thermally connected to the roof.

Taking the assumption detailed above, it is possible to draw some conclusions about the requirements of residential buildings. For those where the upper storeys are used for sleeping accommodation, the main requirement within those rooms will be to ensure thermal comfort during the evening and night-time period. Indeed, in many apartment type buildings, a similar rule holds true since the apartments are generally only occupied outside of working hours, so in this case, the occupied period is extended to late afternoon and early morning.

Thermal simulation of an upper storey bedroom in the same house described earlier has shown that, while the roof covering may have an effect on peak day-time temperature, there is very little difference in internal temperature during the important evening and night-time period. Further examining Figure 3 shows that the internal temperature between 20.00 and 08.00 is essentially the same for each of the modeled systems.

The only significant difference which was observed when assessing night-time temperatures is the effect of thermal mass, whereby a thermally massive tile roofing system holds the heat from the day and re-radiates this during the evening, giving higher temperatures internally in the evening than a thermally responsive metal roofing system, irrespective of the thermal reflectivity of that system.

An assessment of hours-over-temperature for the simulated building, in Athens, but only assessing night-time hours, has shown that there is negligible difference between a standard metal roof and a cool metal roof, although each gives less hours over temperatures between 24°C and 30°C than the equivalent tile roof. If cooling were fitted with a set-point of 20°C in the evening and night time only, then the cooling load for the cool metal roof is calculated to be 9% lower than for the tile roof due to the thermal inertia effect.

In cases where the internal peak temperature in the middle of the day is important, for example where the upper-storey room is used as a home office, then there is a significant benefit from the highly reflective roofing material, although this is, as discussed earlier, only relevant for regions with relatively low insulation requirements.

2.2.2. Office

The main difference between residential and office buildings is essentially in their occupancy regimes and so in the requirements for their internal environments. Again, it is important to consider that only the office space closest to the roof will see any significant benefit from cool roofing and this will be limited where high levels of insulation are used.

Most office buildings (and other similar use-type buildings such as schools) are occupied during the working day. This varies slightly between European cultures, but can be equated to around 08.00 to 18.00 in most cases. As was demonstrated earlier, particularly with reference to Figure 3. the peak day-time temperature can be reduced significantly by using a cool metal roof. The modeled case shown in Figure 3. is in Athens, but this same conclusion would hold true in many Southern European locations.

Figure 4. shows an hours-over-temperature analysis for the same simulation in Athens, again assuming a U-value of the roof of 0.50 W/m^2K. In this case, the analysis looks at all hours (day and night) and while there is very little difference between the conventional metal and tiled roofs, the highly reflective metal roof shows a significantly lower number of hours of over-heating.

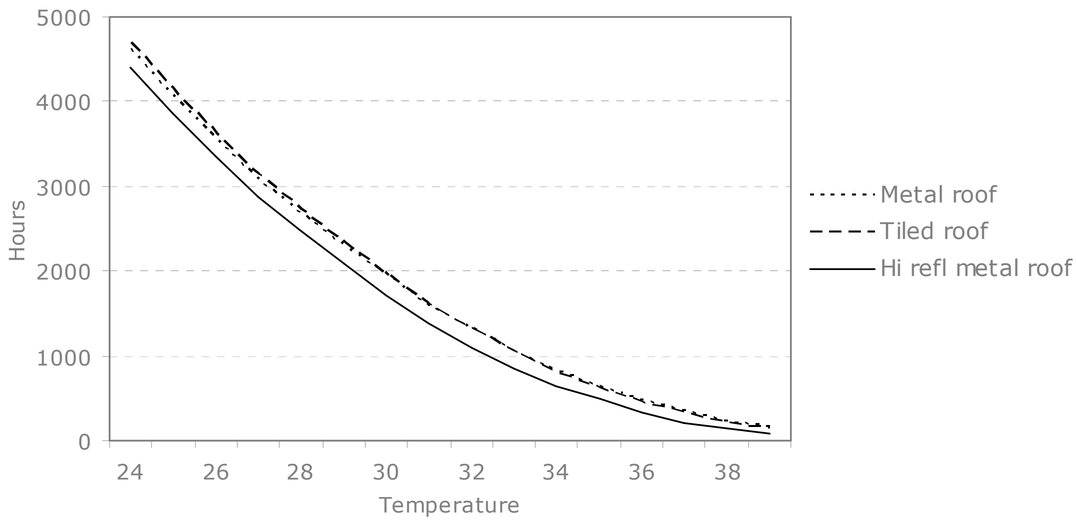


Figure 4. Assessment of overheating for an upper-storey room in Athens, considering all hours and modelled with a conventional metal and tile roof and with a cool metal roof

2.2.3. Warehouse Or Industrial Building

Most warehouses and industrial buildings are large-span, single-storey buildings. Indeed, such buildings are often used for a variety of uses, including sports facilities and shopping centres as well as the more traditional industrial or storage uses. Since these are large open spaces, the occupied area is open to the roof and so changes in internal temperature of the roof could directly affect thermal comfort.

Despite warehouse buildings having good thermal connection between the interior of the roof and the occupied spaces, the thermal requirements in such buildings tend to be very low and in most cases mechanical cooling is not used. Most buildings of this kind are not open to the public and are sparsely populated and it is generally accepted that they will over-heat somewhat during the sunniest summer days.

One factor which can make a significant difference in buildings such as this is the extent of rooflights used. In typical metal-roofed warehouses, between 10 % and 20% of the roof may be translucent rooflights and this has a dramatic effect on reducing lighting requirements, but it also leads to greater levels of solar gain. This solar gain is beneficial at some times of the year, but can potentially lead to over-heating in the summer months.

A simulation of a warehouse building has shown that, in most cases modeled, over-heating would not be considered to be a problem even where up to 12% rooflights are used. The building model was run for London, Strasbourg, Warsaw and Naples and only in Naples was there any cause for concern in terms of over-heating. However, when assessing the warehouse building in Naples, the majority of the over-heating could be eliminated by the use of good ventilation.

For the purposes of this study, a practical approach was taken to ventilation and it was assumed that all personnel and cargo doors would be opened when the temperature rose above 24°C. Figure 5. shows the dramatic effect on over-heating of adding in ventilation. When a cool roof is added in addition to the ventilation, it has a much smaller, but still noticeable effect. However, in all cases, there is still an over-heating effect and in areas such as Naples, consideration should be given to using lower levels of rooflighting, although this is to be balanced against the positive effect that rooflighting has on electricity use. The same study concluded that the total CO_2 emissions associated with heating and lighting the warehouse building in Naples were 35% lower where 12% rooflights were used than if only 5% were used and this benefit must be weighed against the potential over-heating effect.

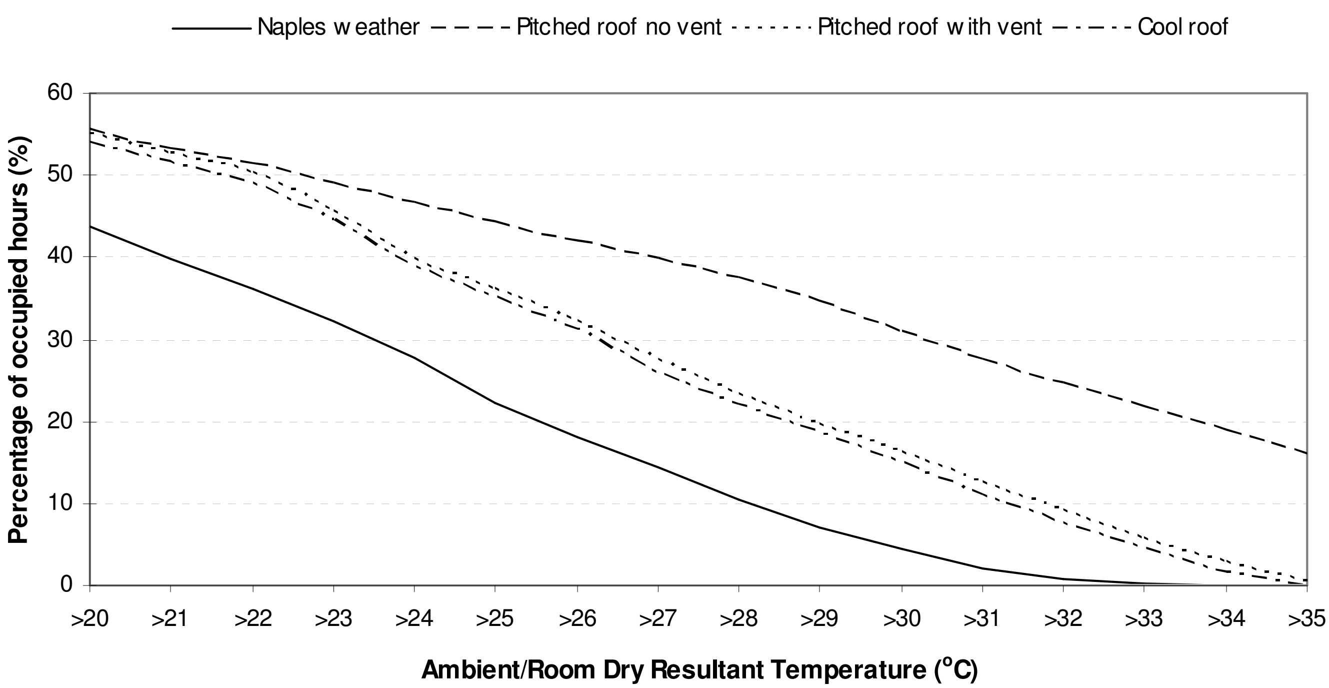


Figure 5. Overheating assessment for a warehouse in Naples with 12% rooflights, roof U-value 0.55 W/m^{2}K showing the large effect of ventilation and the smaller but still noticeable effect of adding a cool roof

From the analysis reported here, it can be concluded that, again subject to the same considerations as earlier regarding local weather and insulation use, cool metal roofing can have some positive impact on thermal comfort within warehouse buildings, although the effect is much less significant than providing sufficient natural ventilation or optimizing the rooflight area. For this reason, and due to thermal comfort not being a great concern for buildings such as this, it is unlikely that cool metal roofing will see significant usage in warehouses, except possibly in the most Southerly parts of Europe.

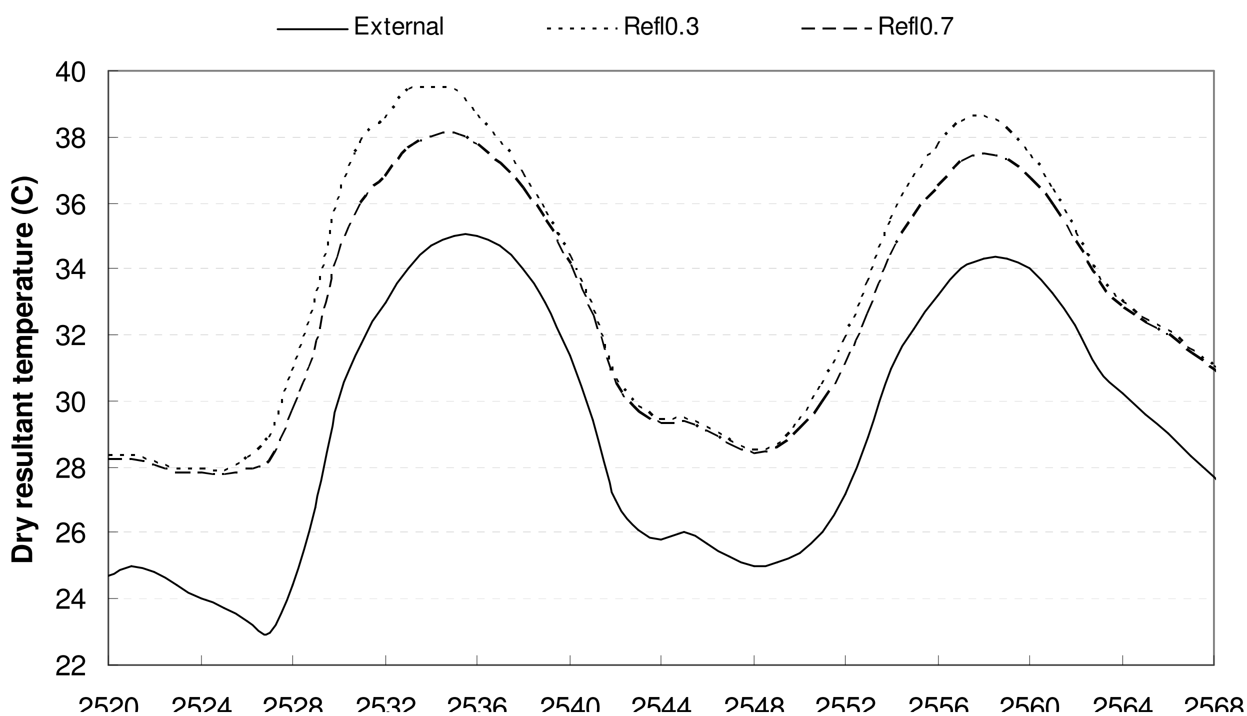
2.2.4. Animal Housing

A final building type which may be of interest is animal housing. In most locations, the regulations relating to agricultural buildings are different from buildings which are intended for human occupation and so most agricultural buildings are not necessarily insulated. This lack of insulation is one factor which might make animal housing a suitable candidate for cool metal roofing.

There is also common acceptance that over-heating in animal housing can be a major problem and there is a wide literature relating to animal welfare and productivity and their dependence on climate in internal animal housing. There is also a growing trend in Europe towards keeping livestock in internal environments for increasing periods.

A computer simulation has been carried out on a livestock building, including heat gains from cattle and relevant ventilation. The simulation was carried out in Trapani, Italy and showed that, despite the high level of heat gains from the cattle themselves, the peak internal temperature could be reduced by around 2°C on a summers day. Indeed, the same effect will be observed throughout the year whenever solar radiation levels are high and also in all locations, depending only on solar radiation, rather than insulation practices. This reduction in peak temperature could have a significant impact on animal welfare and potentially on productivity, although field trials will be required to validate this finding.

Figure 6. shows the internal temperature in the modeled livestock building over a 2-day period in August and clearly indicates the benefit in reducing peak temperature from the cool roofing.



2.3. Mapping Out The Applicability Of Cool Metal Roofing In Europe

The discussion above has shown some of the key considerations for determining where cool metal roofing might be most applicable in Europe. From this, it is possible to draw some conclusions which are summarized in Figure 7. Firstly, cool metal roofing is only of significant benefit where usage patterns dictate that thermal comfort within the daytime is important within the building. For this reason, cool metal roofing is more likely to be beneficial on day-time occupied buildings such as offices or schools rather than on residential buildings. Likewise, if thermal comfort is not a great concern, as is the case in most warehouse type buildings, then cool roofing will not be widely valued, although the application of cool metal roofing to such buildings, at only marginal cost difference, could make some difference to the internal working environment. However, in the case of livestock housing, where thermal comfort is well understood and valued, cool metal roofing could be widely applicable.

Secondly, the use of high levels of insulation tends to isolate the internal and external environments, so reducing the beneficial effect of cool metal roofing. However, where only modest levels of insulation are used, the benefit of the cool roof can be noticeable. It so happens that lower levels of insulation tend to be used in areas where overheating is likely to be of most concern.

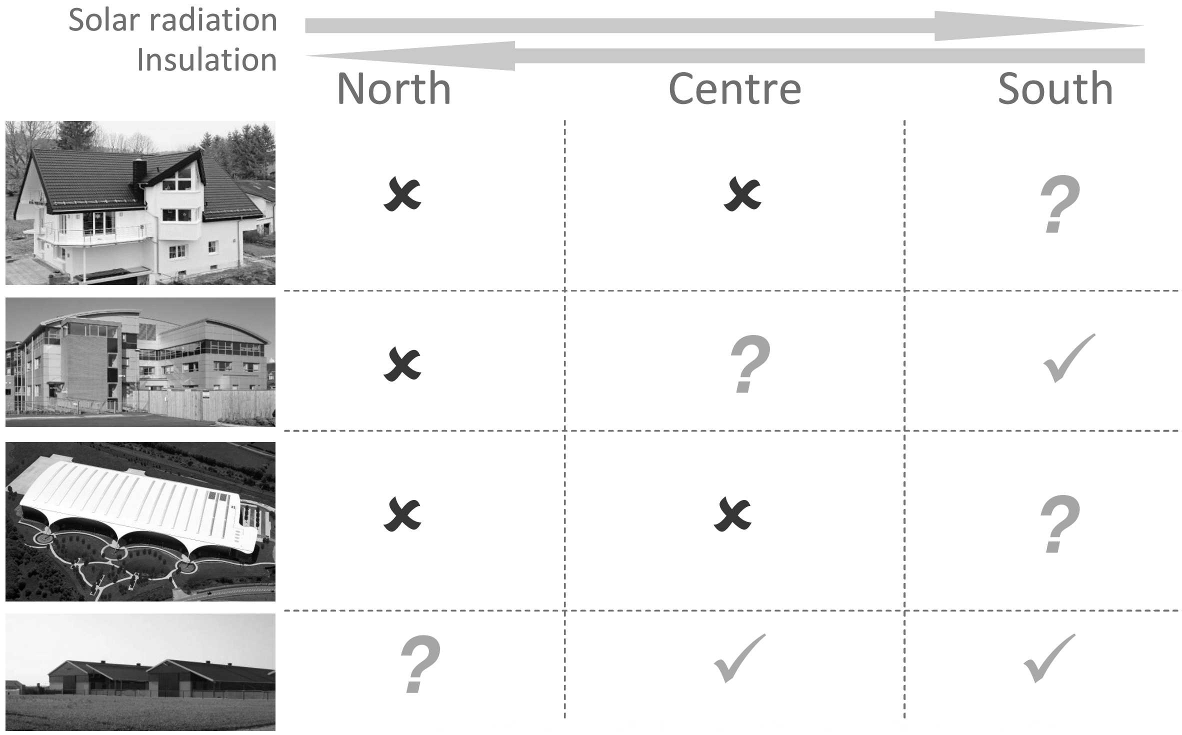


Figure 7. a pictorial representation of the most relevant uses for cool metal roofing in Europe, considering both building type and location. The locations on the matrix marked with a '?' may benefit in some cases from cool metal roofing which should be considerd on a case-by-case basis.

3. THE URBAN HEAT ISLAND EFFECT

In the previous section, we discussed the benefits of cool metal roofing in terms of its effect on the internal environment of buildings. However, potentially of more significance is the effect that this technology can have on the macro-climate.

The urban heat island effect (UHI) is now well studied and it is widely accepted that urban areas are hotter than rural areas and hold heat far more. This is largely due to three factors:

- The lack of vegetation in most urban areas
- The high amounts of thermally massive construction materials used in most urban areas which tend to store day-time heat through the night
- The dark, thermally absorbing surfaces used in many urban areas, particularly on roads and roofs

There is no one solution to the UHI phenomenon. However, cool metal roofing can play a part in tackling the 2nd and 3rd points mentioned above. Figures 2 and 3 shown previously exhibit the dramatic difference between maximum day-time temperature of a cool metal roof compared to a tile roof. This difference is obviously highest where there are high levels of incident sunlight, but it can be seen that, on the particular day in question, the effect was even greater in Strasbourg than in Athens, with the roof surface being predicted to be over 20°C cooler in Strasbourg for the cool metal roof than the tile roof.

In addition to the significantly lower peak temperature, the cool metal roof also cools down much quicker in the evening than a thermally massive tile roof, so the temperature differential is noticeable in Figure 2 all the way until 04.00 in the morning.

The benefits of cool metal roofing in helping to mitigate the UHI effect are independent of building type and are equally applicable in urban areas throughout Europe. However, possibly the largest individual gains could be achieved from the use of cool metal roofing on warehouse and industrial type buildings (including for example shopping centres and sports halls) in urban areas where the large roof areas provide the opportunity to have a significant effect.

When discussing the benefits of cool metal roofing towards thermal comfort and potentially reduced cooling costs, the benefits to the building owner are obvious and can be quantified. However, where cool metal roofing is used to help mitigate the UHI effect, the benefits are not immediately apparent to the building owner, but are more relevant to the surrounding society. For this reason, cool metal roofing is only likely to find widespread use as a UHI mitigation agent if local legislation requires consideration of this factor in new build or refurbishment projects. At present, there is no European legislation of this type.

4. CONCLUSIONS

Cool metal roofing is a technology which is now only just starting to become established in Europe. However, the results of market studies and building simulation have shown that there are certain combinations of building type and location to which cool metal roofing is most applicable.

In terms of the effect on the internal environment of buildings, use pattern is very important and here, it was found that buildings used extensively in day-time hours, such as offices and schools, could benefit from cool metal roofing, particularly where upper-storey rooms are occupied or in single-storey buildings. Another area with much potential for cool metal roofing is in livestock housing where significant internal temperature reductions can be demonstrated, although further work is required to fully understand the quantifiable effect on animal welfare and productivity.

Finally, irrespective of building type, cool metal roofing has been shown to have potential in mitigating the urban heat island effect due to the combined factors of reduced peak temperatures and low thermal mass.

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