TECHNICAL PAPER

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Prepainted Metal Roofing for Low Energy Buildings



ecca

prepaintedmetal.eu

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Prepainted Metal Roofing

Prepainted metal is a high quality product manufactured under strict quality control in the coil coating process. The main substrates for prepainted metal are steel and aluminium strip and these are usually coated with a liquid paint by roller-coating, although sometimes a pre-formed film is laminated to the surface and occasionally a powder-paint is applied in coil coating.

A prepainted metal product is a synergistic combination of the metal substrate, any metallic coating which may be used, an efficient cleaning and chemical conversion process and usually 2, but up to 4 different paint coatings. The coil coating process allows different coatings to be used on the two sides of the metal strip, so the possibilities are endless.

Each producer of prepainted metal offers their own, sometimes branded, selection of prepainted metal products. It is beyond the scope of ECCA to compare all of these products, but this ECCA Technical Paper attempts to provide a guide to the main product types, together with their main uses, advantages and disadvantages.



Image: Fotolia

Roofing Systems

Most industrial, warehouse and large commercial buildings are formed from a frame construction with large spans giving wide open enclosed spaces, configurable for many uses. In recent years, the production of such buildings has evolved into a highly efficient industry and increased global trade flows have demanded increasingly sophisticated warehouses.

For many such buildings, prepainted metal is the obvious candidate both for cladding the walls and also to provide a weatherproof roof covering. For the roofing of such buildings, there are two main systems in use in Europe today:

- Metal roofing systems;
- Built-up flat roof systems.

The two types of roofing system are not entirely equivalent, since they would be used with different structural frame types. However, in that they provide the weather-proofing for large wide-span structures, they perform an equivalent role and one could be substituted for the other in most projects.

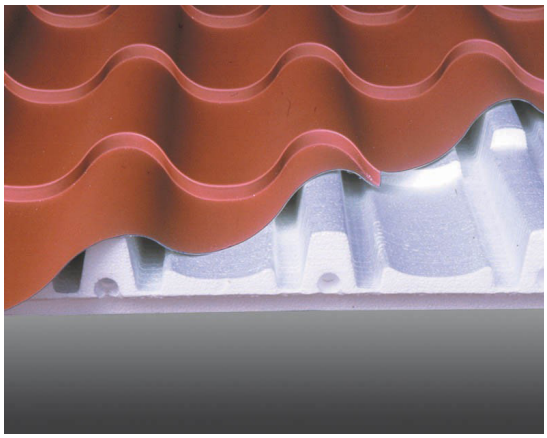


Image courtesy of Tata Steel

Metal roofing systems can be either one-piece or built up on-site, but invariably consist of two sheets of profiled metal with insulation material sandwiched between. In the case of composite or sandwich panels, the two metal skins are adhesively bonded to a solid insulation core which is usually a polyurethane foam. However, metal roofing is often built up on-site, firstly attaching a metal liner sheet to the framework, with spacers between this and the outer sheet providing a space for loose-fill insulation such as glass or mineral wool. In each case, the roofing system is attached to purlins which span between structural frame elements. Roofing systems like this are most frequently used on roofs with a slope of between 5° and 10° to give adequate drainage.

Built-up flat roof systems are generally used on flat roofs or those with a slope of less than 5°. In this case, structural decking is used to span between frame elements and the roofing system is built up on top of this. A vapour barrier is usually laid over the decking and solid insulation laid over this. The waterproofing is applied on top of this insulation. Traditionally, waterproofing has been bitumen, usually applied with a flame. However, more recently, plastic waterproofing films such as single ply membranes have been used which are usually heat-sealed at overlaps to provide a weatherproof membrane over the surface of the roof.

An equivalent level of insulation can be achieved with either of these roof systems and with good attention to detail, either will provide both good waterproofing and an air-tight building envelope.

One area where these two roofing techniques differ is in the ease of incorporating other systems into the roof. A good example is roof-lights.

For wide-span, single-storey buildings, roof-lights provide a very efficient means of allowing natural light to penetrate deep into the building. For metal roofing systems, roof-lights can be incorporated simply by replacing sections of the profiled metal roofing with translucent sheets with the same profile. These are typically made from GRP or similar materials. This does not impede water flow on the roof and makes no additional requirement on the structure.

If roof-lighting is to be incorporated into a built-up flat roof, it presents more difficulties. Firstly, any penetrations into the continuous waterproofing membrane are required to stand proud of the roof surface to avoid water penetration. In addition, since the decking used in these systems is structural, where penetrations are made, additional structure is required to support the roof-light and it's up-stand.

A study by the Department of Architecture at Oxford Brookes University has shown that the complexity of incorporating roof-lights into built-up flat roofing systems contributes greatly to their cost and is probably the reason that buildings with this kind of roof tend to use less roof-lights than those with metal roofs. The same study, reported here, shows that roof-lights contribute significantly to the energy-efficiency of such buildings.



Image courtesy of ArcelorMittal

Cost of Roofing Systems

The starting point for the Oxford Brookes study into the energy performance of industrial and warehouse type buildings was to investigate the cost of different roofing systems and how the incorporation of energy-saving features such as roof-lights would affect this cost. Actual costs are very difficult to pin down, but using reliable estimates, it can be seen that metal roof systems prove to be significantly cheaper.

Costs were estimated for two systems. The estimates were based on published data used for cost estimation, together with information from suppliers of flat roof and roof-light systems.

System 1 – the low-pitch metal roof

Built-up metal roofing system (trapezoidal steel sheet, insulation, inner steel liner) fixed to purlins including spacers and associated components, with 12% factory assembled triple layer in-plane rooflights.

- Roofing 49.43€ per m^2
- Rooflights 68.04€ per m^2

System 2 – the flat roof

single layer membrane on insulation and vapour control layer laid on 60mm trapezoidal steel decking fixed to purlins, with 5% triple skin polycarbonate roof domes.

- Roofing 81.87 € per m^2
- Rooflights 314.57 € per m^2

It can be seen that even in the absence of roof-lights, the low-pitch metal roof is a more economical option. The cost of incorporating in-plane roof-lights into the metal roofing system was found to be only 38% higher then the cost of the bulk roofing system, but in the case of the flat roof, the cost of incorporating roof-lights was found to be 284% higher.

The cost of incorporating roof-lights into flat roofing systems is very high. This is, at least in part, the reason why, when roof-lights are used on flat roofs, their use is kept to a minimum. However, where a metal roofing system is used, the inclusion of higher levels of roof-lights does not incur such a high initial cost penalty and will be repaid in lower lighting energy bills.

For a typical warehouse-type building, dimensions 40m x 60m, with a total floor area of 2,400 m^2, the total cost of the roofing system with 12% roof-lights (for the low-pitch roof) and 5% roof-lights (for the flat roof) on the basis of this estimation is as follows:

- Low-pitch prepainted metal roof with 12% in-plane roof-lights: 124,635.00 €
- Flat roof with 5% up-stand roof-lights: 223,734.00 €

The total cost of the metal roofing system is 45% lower than the flat roof, while the roof-light element is nearly 50% less, despite the low-pitch roof including 2.4 times more roof-lighting than the flat roofing system.

In summary, low-pitch metal roofing systems are not only cheaper than flat roofing systems, but become significantly cheaper when energy-saving features such as roof-lights are incorporated. Choosing a low-pitch metal roof with a high level of roof-lighting, such as 12% is a cheaper option than an equivalent flat roof system, even when only a small roof-light coverage is used and, as the Oxford Brookes study went on to show, can save energy in the operation of the building too.

Energy Usage in Industrial and Warehouse Buildings

As for all buildings, industrial and warehouse buildings use energy for heating and lighting. Except for special cases (for example, temperature-controlled warehouses) cooling is not generally used in these kinds of buildings.

The building envelope and in particular the roof can have an impact on both heating and lighting requirements. The requirement for heating is influenced by heat-loss through the roof, which is a function of insulation and air-leakage. However, all roofing systems are capable of incorporating any required level of insulation and air-tightness is, to a large extent, determined by site practice in providing adequate seals to either the vapour barrier or the internal sheet of the system. Using good work practices, high levels of air-tightness can be generated with either metal roofing or flat roof systems.

Incorporating roof-lights into a wide-span roof can affect both the lighting and heating requirements of a building. Roof-lights allow light to penetrate the building and so if suitable controls are fitted then artificial lighting can be turned down or off appropriately, saving lighting energy.

Roof-lights have a complex effect on thermal performance. They increase solar gain within the building, thereby increasing the air temperature. However, they also tend to have a lower insulation level than the rest of the roof, so heat can also escape. The net effect depends on the solar transmission and insulation level of the roof-lights, but using typical values, this can be calculated.

Finally, of course, the increased solar gain from roof-lights can potentially cause over-heating during the summer months and particularly in the hotter parts of Europe this could be a concern.

When considering the effect of roof-lights, the impact is proportional to the area of roof-lights used. This is typically expressed as the proportion of the roof area covered with roof-lights. In the study reported here, aerial photography of various industrial and warehouse buildings has been used to assess standard practice. It was found that, where flat roofing is used, roof-light density would typically be around 5% whereas where a metal roofing system is used, around 12% roof-lighting is typically adopted. The Oxford Brookes study reported here assesses the impact of this difference on the overall energy balance for a typical warehouse-type building.



Image courtesy of BASF

The OISD Study

This Technical Paper reports the results of a study by the Oxford Institute for Sustainable Development (OISD) at Oxford Brookes University in the UK. This study was aimed at assessing the differences in energy performance of industrial and warehouse buildings with either metal roofing or an alternative, flat roofing system.

Following assessment of common practice around Europe, the study identified that the primary differences in energy performance of metal roofed and flat roofed buildings would be related to the pitch of the roof and the ease of incorporation of roof-lights and their effect on the energy balance.

Computer simulation was performed to assess the energy performance of two modelled buildings of equivalent dimensions, the only difference being that one had a metal roof, with a pitch of 6° and in-plane roof-lights covering 12% of the roof area, while the other had a nominally flat roof and up-stand roof-lights covering 5% of the roof area. The simulation was carried out using IES software, incorporating daylight analysis.

A daylighting analysis was first performed, following which results of this were fed into the energy model. Conservative assumptions were made about lighting and heating efficiency and set-points and insulation values were chosen to be typical of regulatory requirements for new construction in the modelled locations. The model was run using weather data and relevant building parameters for:

- Warsaw
- London
- Strasbourg
- Naples

In each case, data was collected for a full year on heating, lighting and internal temperatures.

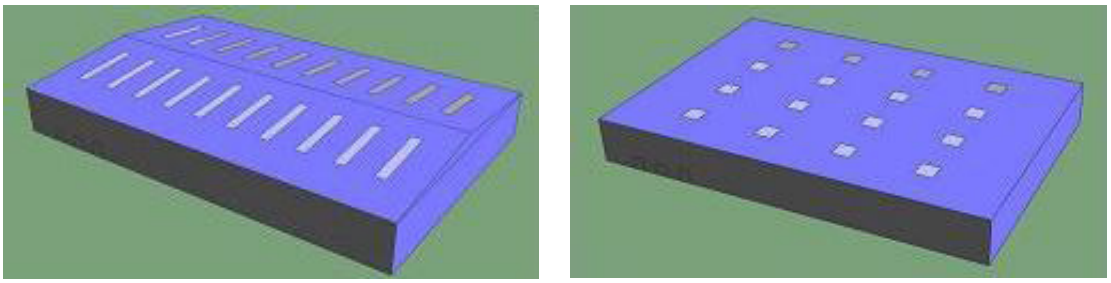


Figure 1 - Images of the buildings modelled in IES.

Lighting

As expected, using the higher level of roof-lights on the metal-roofed building gave a proportionately higher daylight factor within the building of 5% compared to only 1.8% daylight factor for the flat-roofed building.

Daylighting maps were created to show how the 12% roof-light situation gave a relatively even distribution of light across the floor area, while with only 5% roof-lights, as typically used in flat-roofed buildings, there were more dark spots.

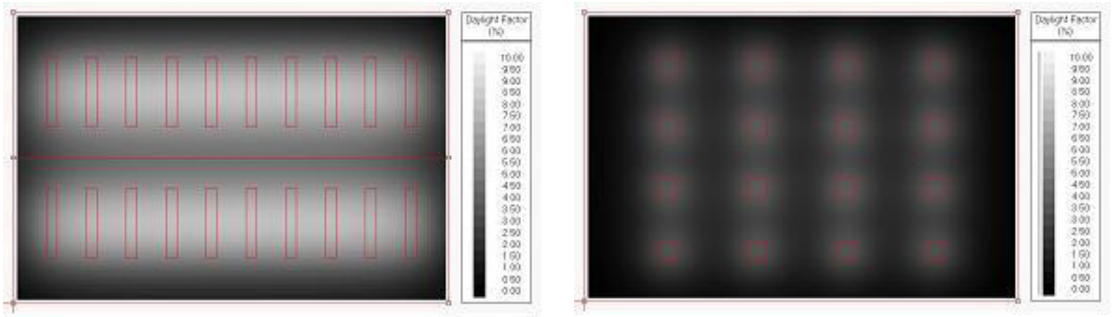


Figure 2 - Day-lighting distribution at ground level for the two buildings: (left) the metal-roofed building with 12% roof-lights; and (right) the flat-roofed building with 5% roof-lights.



Picture courtesy of P. Andreux (Architect)

Within the computer model, an assumption was made that an automatic lighting system would turn lights off when a lighting level of 300 lux is achieved at ground level. Using this, the two buildings were modelled for lighting energy requirements in each of the four locations and the results are shown in **Figure 3**.

As expected, in all locations, the additional roof-lights reduced the annual energy requirement for lighting. With the modest level of lighting required in such buildings (300 lux) this reduction in lighting energy is proportionately very large, between 50% (for Warsaw) and 65% (for Naples). However, if higher light levels are required for specific purposes in some buildings, then while the proportionate benefit may be less, the absolute benefit will remain the same.

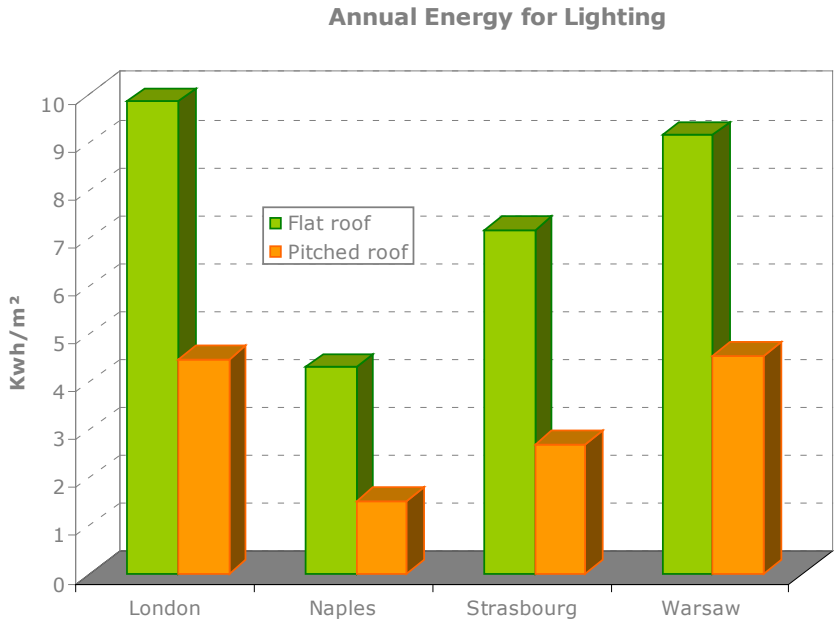


Figure 3 - Comparison of lighting energy requirements for the flat-roofed and metal-roofed buildings with 5% and 12% of roof-lights respectively

Heating

As discussed earlier the impact of additional roof-lights on the heating requirements of the building is complex since roof-lights increase solar gain, but at the same time, they lose heat since they provide less insulation than the remainder of the roof. This balance of effects was also studied within the OISD computer simulation.

Figure 4 shows the difference in heating requirements between the metal-roofed and flat-roofed buildings with 12% and 5% roof-lights respectively. Here we can see that, although the effect is quite small, in most cases the net impact is to increase overall heating requirements. The exception is Naples where increased solar gain actually out-weighs the lower insulation of the roof-lights. Of course the building modelled in Naples was assumed to have poorer insulation in the roof than the others anyway (U value of 0.55 W/m^{2}K) so it is not surprising that the insulation properties of the roof-lights had proportionately less effect.

In the case of the building modelled in Naples, total annual heating energy requirement was actually 20% less for the metal-roofed building than the flat-roofed, whereas in London the heating requirement was 13% more. The net effect of the roof-lights was much more balanced in both Strasbourg and Warsaw with heating penalties of only 2% and 3% respectively.

As with any computer modelling, the results depend somewhat on assumptions made in the model, including heating set-points and operating hours. However, while these will alter the proportionate effect, the absolute effect of incorporating the higher level of roof-lights made feasible with metal roofing will remain the same.

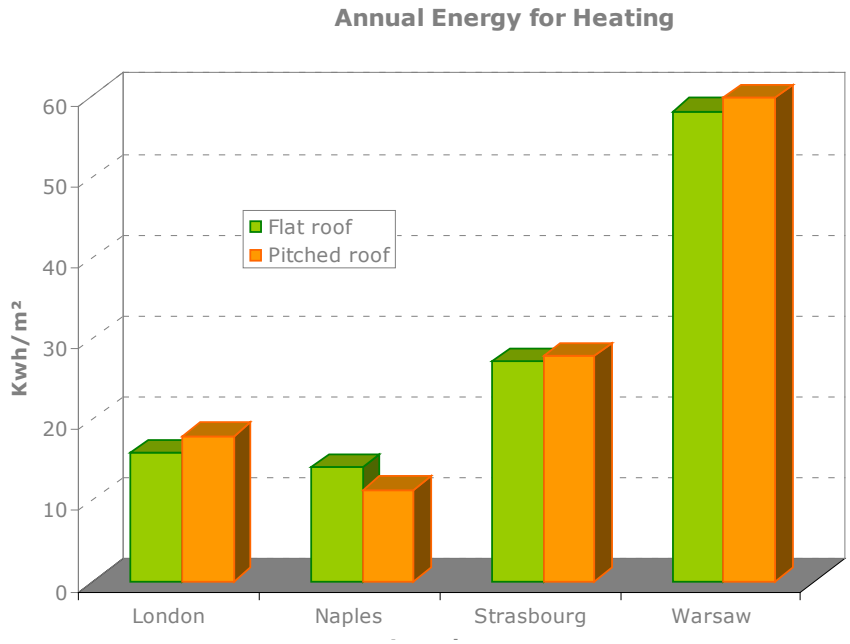


Figure 4 - Comparison of heating energy requirements for the flat-roofed and metal-roofed buildings with 5% and 12% of roof-lights respectively

The Energy Balance and CO_2 Emissions

The typical practice of incorporating higher levels of roof-lighting into metal-roofed buildings has been shown to decrease the lighting requirement, but in most cases it has a small penalty on heating. The OISD study also assessed the combined effect on total energy usage and, by converting this with standard conversion factors on the CO_2 emissions associated with them. A European standard conversion factor was used for electricity and it was assumed that heating would come from natural gas.

Figure 5 shows the combined effect of heating and lighting on overall CO_2 emissions, averaged over a year, for the metal-roofed and flat-roofed buildings in the four locations modelled.

In all cases, there is a significant reduction in overall CO_2 emissions associated with the energy balance of the building.

For the building modelled in Naples where there was a positive effect from both heating and lighting, the overall reduction in CO_2 emissions was found to be 35%, while in London the benefit was 22% and in Strasbourg, 18%. The building modelled in Warsaw had a much higher heating requirement than any of the others and so the proportionate benefit of 8% is smaller, although this still represents an overall CO_2 emissions reduction of over 1.5 kg per m^2.

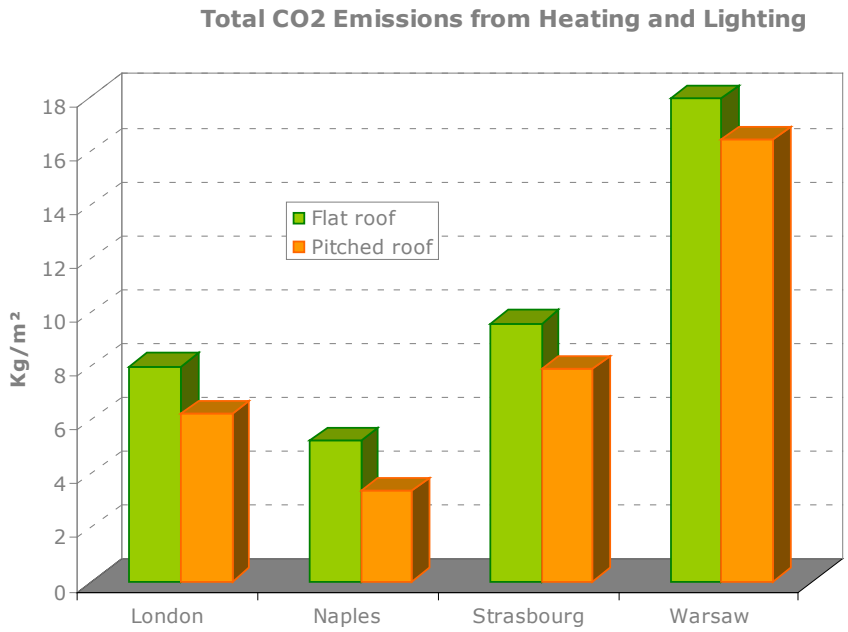


Figure 5 - Comparison of overall CO_2 emissions associated with heating and lighting for the flat-roofed and metal-roofed buildings with 5% and 12% of roof-lights respectively

The Effect of Solar Gain

Whilst it has been shown that additional heat gain through higher levels of roof-lights can have a beneficial effect on heating requirements, there is a danger that increased heat gain could lead to overheating during the summer months. For this reason, the OISD study also assessed overheating potential.

For an unventilated building, it was found that the maximum temperature achieved within the building could be up to 8^0C higher. However, common practice in buildings such as this would be to increase natural ventilation by opening cargo doors on hotter days. By making this assumption, the difference in maximum temperature was found to be only between 2^0C and 3^0C.

A more important measure of overheating than maximum temperature is to assess the number of occupied hours for which the building is above a certain temperature. **Figure 6** shows time-over-temperature plots for the two modelled buildings in each of the four locations studied. In all cases, ventilation is assumed. From this it can be seen that, although the metal-roofed building is hotter in all cases, the only case where overheating is a significant concern is in Naples.

In the case of a building located in Naples (or similar locations) internal thermal comfort may dictate that lower levels of roof-lighting are used, even though the higher levels of roof-lights can significantly reduce overall energy consumption. If this is the case, then the lower levels of roof-lighting could be achieved using a flat roofing system, although the same result could also be achieved with metal roofing, again with a lower cost.

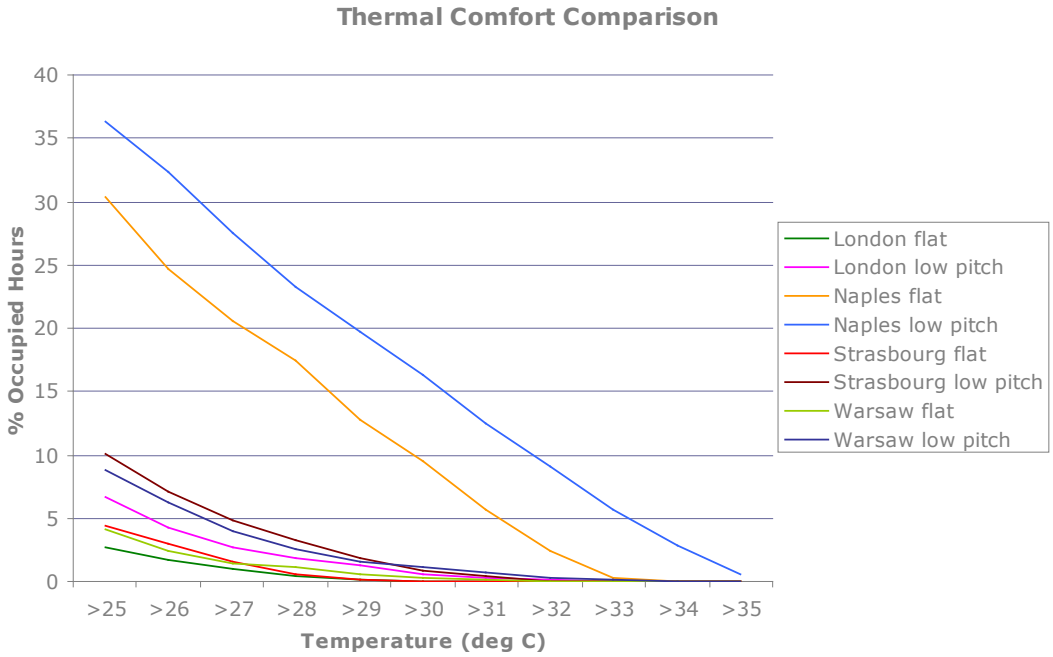


Figure 6 - Hours-over-temperature plots for the flat-roofed and metal-roofed buildings with 5% and 12% of roof-lights respectively in each modelled location

Conclusions

In assessing the difference in energy efficiency of metal-roofed and flat-roofed industrial and warehouse type buildings, it was found that in most respects, such buildings could be designed and constructed to perform similarly. However, one significant difference is the ease and cost-effectiveness of incorporating roof-lights into the metal roofing system. This results in higher levels of roof-lighting typically being used for metal-roofed buildings which can have a dramatic effect on overall energy consumption.

The study reported here showed that metal-roofed buildings would tend to use translucent roof-lights for around 12% of the roof surface, while where they are used, roof-lights would typically cover only 5% of the surface of a flat roof. This is partly due to the difficulty of installing roof-lights on a flat roof, with the requirements for up-stands and additional structure to support the roof-lights and partly due to the cost increase associated with this. For a flat roof system, each m^2 of roof-light typically costs over 280% more than the rest of the roof, whereas for the metal roofing system, the incremental cost of roof-lighting is less than 40%.

Using the higher level of roof-lights as is typically used with metal roofing systems not only gives a more uniform natural light distribution within the building, but also reduces the energy requirement associated with this by up to 65%. The effect on heating is much more complex, but there is usually a small heating penalty due to the lower insulation value for roof-lights than the remainder of the roofing system. In almost all cases, this increased level of roof-lighting does not cause any over-heating concerns, although in the far South of Europe, it may be necessary to use lower levels of roof-lighting to keep internal temperatures to an acceptable level on the very hottest of days.

Taken all together, the net effect on the energy consumption of buildings is that incorporation of roof-lights at a level typical of metal-roofed buildings, in all cases, reduces the overall energy consumption and so reduces the associated CO_2 emissions. For the locations modelled, overall CO_2 emissions associated with heating and lighting could be reduced by between 8% and 35% by increasing roof-light coverage from 5% to 12%, as would be typical of a metal-roofed building.

Not only can the use of a low-slope metal roof with in-plane roof-lights save energy, but it is actually cheaper than an equivalent flat roofing system and the cost benefits stack up even more when the proportion of energy-saving roof-lights is increased. Using metal roofing truly presents a win-win-win situation for lower energy use, lower CO_2 emissions and lower cost.



Picture courtesy of Alucoil







Pictures courtesy of ArcelorMittal (1-3) and Novelis (2)

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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