Lightweight Sandwich Panels in Cold Stores and Refrigerated Warehouses

Bachelor's thesis

Construction Engineering

Visamäki, autumn 2013

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Visamäki
Construction Engineering
Steel Design and Construction

ABSTRACT

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Subject of Bachelor's thesis Lightweight Sandwich Panels in Cold Stores and Refrigerated warehouses

ABSTRACT

The use of sandwich panels has gained considerable recognition in the construction industry and more use of this composite structure is ever increasing. This study highlights and familiarizes the use of lightweight sandwich panel in refrigerated warehouses and cold storage facility and construction and the challenges such construction faces in warm climates considering the effects of thermal load.

The study was commissioned by HAMK Sheet Metal Center, the steel research and development center in Hämeenlinna. The objective of the study was to investigate the thermal load on lightweight sandwich panel and how this load affects the working of the structure. Another aim was also to provide a structural arrangement that would reduce the effects of this loading on the structure. The loading is the thermal load of the sun, and the effects of this load are deflection of the span, wrinkling of the face, and core deformation, others include the shear failure of the screws and the stress induced by bending and intermediate supports in a multi-span system.

The study is mostly on a general and descriptive level, reviewing and examining existing and current practices on how to reduce thermal load on lightweight sandwich structures and providing ways to improving and modifying them. A thermal break, covering over the face of the panel, the use of flexible screws, sealing at the joints are existing practices geared towards reducing the effect of thermal load.

The study provides further measures of reducing the thermal load by incorporating additional insulation on the panel face, further reduction of thermal bridge by using short screws rather than go-through screws from panels to the supporting structure and the use of PVDF paint as polymeric membrane.

Keywords: Lightweight, Sandwich panel, Refrigerated warehouses, Cold stores, Thermal load and deformation.

Pages: 35 pp.

CONTENTS

1 INTRODUCTION

The use of lightweight sandwich panels in cold stores and refrigerated warehouse facilities is gaining considerable familiarity and acceptance in today's food storage facilities. Some manufacturers are making promises of high efficiency, durability and ease of fabrication in its use. However, its use in this regard still poses some problems such as large deflections and high stresses in the panels due to the difference in both the external temperature of the surrounding environment and the internal temperature within the structure.

In view of the problem associated with thermal gradients in a sandwich panel's designs, the study aims and objectives are to find out the thermal loads on lightweight sandwich panels, to find out the effects of thermal loads on lightweight sandwich panels, and to find a solution that minimizes the effects of thermal loads on lightweight sandwich panels achieve the following objectives;

The research question was formulated based on the objectives of the study and as thus is divided into two parts.

What effects do thermal loads have on lightweight sandwich panels?

What structural solution of lightweight sandwich panel would minimize the effects of thermal load to make it suitable for use in cold stores and refrigerated warehouses

2 BACKGROUND

Sandwich panels have gained acceptance in its use as a structural system in the construction industry. Its usage is as old as mankind, and more research is being conducted to find more uses of sandwich panels in other areas.
In its totality, a sandwich panel is basically composed of two faces and an enclosing core. The core material is normally a low strength and low density material that helps to distribute and absorb impacts. The core shear strength and stiffness are properties worth considering in the design of the sandwich structure. The presence of the core significantly increases the moment of inertia of the cross section of the outer faces and thus enables them to work together as a single beam (Pokharel 2003).

The face of a sandwich panel can be any of the following listed materials, thin or thick faced metal sheet, thick fibre reinforced composite material. However, there are numerous other face materials some of which add bulkiness to the structure, example is concrete

Figure 1 below shows the structure and material of a lightweight sandwich panel.

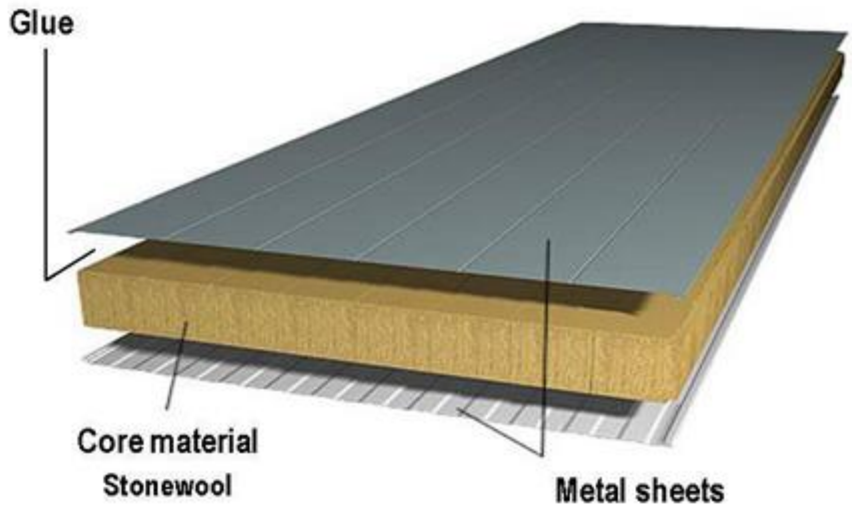


Figure 1 Sandwich panel (thin faced, made of metal sheet) with stone wool core material (sandwich construction)

2.1 Lightweight Sandwich Panels

A lightweight sandwich panel is a composite structure which has a high strength to weight ratio and is usually composed of sheet metal faces, hence its lightweight characteristics. According to its usage and static behaviour, lightweight sandwich panels can be divided into two categories: thin faced and thick faced sandwich panels (Martikainen 2010). The thin faced panels are further classified into the flat and the lightly profiled faced panels. (see figure 2 on page 3)

The different compositions of materials that make up the lightweight sandwich panel are designed to serve specific functions and they all assist to provide strength (resistance to thermal loads), support, durability and aesthetics for the structure.

2.1.1 Sheet Metal Faces

The sheet metal faces of a lightweight sandwich panel serve a number of purposes. They provide aesthetics, they provide structural stiffness which carries stresses caused by bending moment, and they also protect the more vulnerable core material from environmental effects, mechanical damage and weathering. Axial forces (compressive and tensile) are supported entirely by the faces. The faces carry these stresses caused by bending as normal stresses.

Flat and lightly profiled faces can provide only axial resistance since their bending stiffness is negligible whereas axial and bending moment resistances are provided by profiled faced panels (Pokharel 2003).
However, studies show that the structural behaviour of profiled sandwich panels is more difficult to analyse.

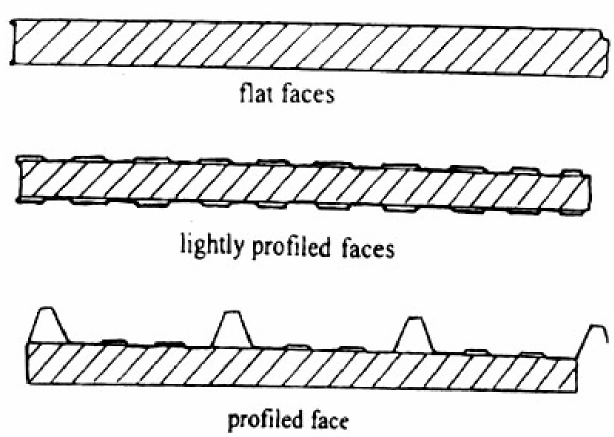


Figure 2 Various faced Sandwich Panels (Pokharel 2003)

2.1.2 Core Materials

The core of a lightweight sandwich panel has many functions. It provides a shear connection between faces, thereby carries shear stresses caused by shear forces. Since the faces of the panel take compressive stress, the critical buckling stress and the ultimate compressive strength of the compressed face are significantly raised by the presence of the core (Pokharel 2003).
The core presents the most important influence in the overall stiffness and flexural rigidity of the structure. It also provides stability and acts as insulation for the entire sandwich system. Core materials should be selected as suitable to carry high shear stresses combined with an efficient insulation property. Thus, it must reflect a good and recommended U (thermal transmittance) value. (U value is discussed in details in Paragraph 3.1)
Various core materials find their uses in sandwich panels nowadays. There are a great variety of cores such as rigid foams hexagonal structures made from thermoplastics, metallic and non-metallic materials, expandable and fireproof materials, balsa wood, etc.

The use of these different core materials is restricted to what it is aimed to achieve and for what purpose it is intended which is the concern of this study.

Lightweight sandwich structures are sensitive to temperature changes, because of the constituent elements and their different thermal expansion coefficients.

The core material of lightweight sandwich panels can be of expanded plastic and mineral wool although other material types also exist.

Table 1 below shows some insulating materials with their thermal conductivity and thermal transmittance properties.

Table 1 Typical insulation thickness for cold stores utilizing different insulation materials (FAO 1994)

Insulation	Thermal,Conductivity (W/m*K)	Thickness (m)	*U-value (W/m^2 K
Polystyrene	0.038	0.220	0.17
**Styrofoam FR	0.035	0.200	0.18
Polyurethane	0.029	0.170	0.17

**Styrofoam is a trademark brand of closed-celled extruded polystyrene foam which is currently being made and used as an insulation material.
Polyurethane is increasingly being used as an insulating core material of load-bearing sandwich panels for refrigerated and cold room facilities. The rigid foam has extremely good elastic properties which makes it suitable in structures used in transportation, as it absorbs high enough stress due to vibrations. Other properties include a good thermal insulation with respect to thermal conductivity which is a necessity for an efficient heat stability in refrigeration and cold room use.

In addition, part of our solution is to provide a suitable sheet metal face which is able to reflect high enough radiant energy from its surface with a view to minimise absorption and transmission of heat energy from the sun into the core material and ultimately into the refrigerated warehouse.

2.2 Design Considerations in Sandwich panels

Sandwich panels are designed according to the European product standard for sandwich panels, EN14509. The Recommendation for Sandwich panels (CIB 2000) stipulates the guidelines for sandwich designs and basically covers the design of metal faced sandwich panels with a core made of the following: rigid polyurethane foam expanded or extruded polystyrene foam, phenolic foam, cellular glass or mineral wool. Fastenings are not a subject for the European product standard. However, it gives the loading arrangements and procedure with which to determine the tensile and shear resistance of both direct and concealed fastenings. (ECCS 2009).

The main components of the sandwich panel are the core and the faces. As a result, in selecting these materials, their properties (mechanical properties) and their heat conduction properties must be well assessed. The factors considered depend on the end use of the sandwich panel; the core material strength (shear and stiffness) and insulation properties, the heat conduction properties, the mechanical strength of the faces, the polishing of the face material and nature of load that the structure is subjected to.

2.2.1 Structural Design Considerations

In this study, the restricting factors are limited to the design of a structure which can withstand the thermal load by the incident radiation of the sun, hence its use as a refrigeration and cold room component for very warm environment.

The main design consideration for this study is to reduce the amount of thermal load on the structure which ultimately causes bending at the joints and supports and shear stresses in the core. Hence a design arrangement that will allow for reduced exposure to direct heat energy of the sun which will significantly reduce the load on the components of the panel and thus enhance durability and efficiency, in addition the design consideration of the core material also plays a crucial role in the design of such a sandwich panel, this is so because the core must be capable to absorb enough heat energy and capable to take compressive loading without undergoing premature failure.

2.2.2 Failure Modes

Sandwich panels have been known to undergo a series of deformation depending on the configuration, the span, the load and the support reactions. For a one-span panel, the sandwich panel is under bending. The inner face, the outer face and the core of the structure are modelled as an I-beam. Since the sandwich is likened to an I-beam, the core material acts as the beam’s web while the skin/faces act as the flange. If the panel is composed of flat faces, thermal action results only in displacement (maximum deflection) and does not cause internal forces. In addition, in the case of a panel with deep-profile faces, bending moments and shear force appear within the structure; deflection from the temperature difference between the internal face and external face result in moment and transverse forces. (Blaszezuk & Pozorski 2011)

However, it appears that one of the most severe problems concerning the survivability of most composites is the bond breakage between their constituents. Such breakage is caused by either extension of pre-existing cracks or by the creation of new cracks at the material interfaces. For example, upon thermal or mechanical loading of the composite, micro-stresses will develop at the interface between various constituents. If these stresses exceed the corresponding bonding strength of the composite they will result in crack formation (Papanicolaou et al. 2009).

In Figure 3a, loading is assumed to be thermal, it can be seen that the upper skin is put under compression due to the mismatch of the difference in temperature of both inner and outer faces, and tension on lower skin. The outer skin can also be assumed to be under a higher temperature range than the upper skin, hence the curvature observed.

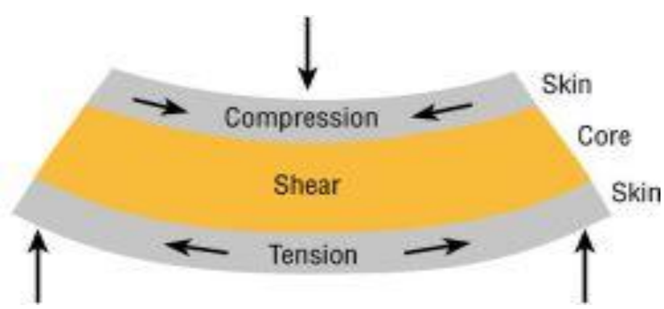


Figure 3a Characteristics of a sandwich panel under thermal load

For continuous multi-plan panel under thermal action, extreme bending moment is attained at the internal support of the panel, such statically indeterminate panel is also loaded by a higher bending moment at the intermediate supports than for one-span panel and in addition by concentrated lateral support reaction. While this is so, Blaszezuk & Pozorski (2011), investigate that intermediate supports reaction is a function of span for the same parameter of the sandwich panel investigated; if the reaction is positive it causes compression at the support and if negative, it causes tension of the screws attaching the panel to the supporting structure.

For flat profiled panels, the first failure mode of long and medium span length panels is usually the buckling failure at intermediate supports due to the interaction between the bending moment and support reaction while for the short span panels; the failure mode is usually the shear failure near the intermediate support (Hassinen & Martikainen 1994, 1996).

Figure 3b below shows the deformation at intermediate support of a continuous sandwich panel

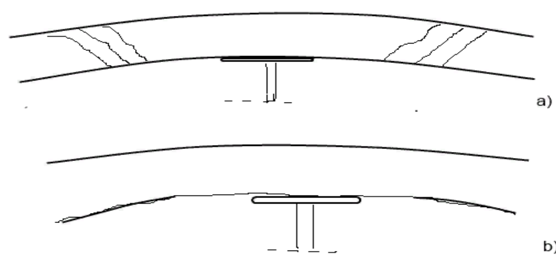


Figure 3b Failure mode of a continuous sandwich panel under thermal load at intermediate supports. a) Core deformation, b) face wrinkling

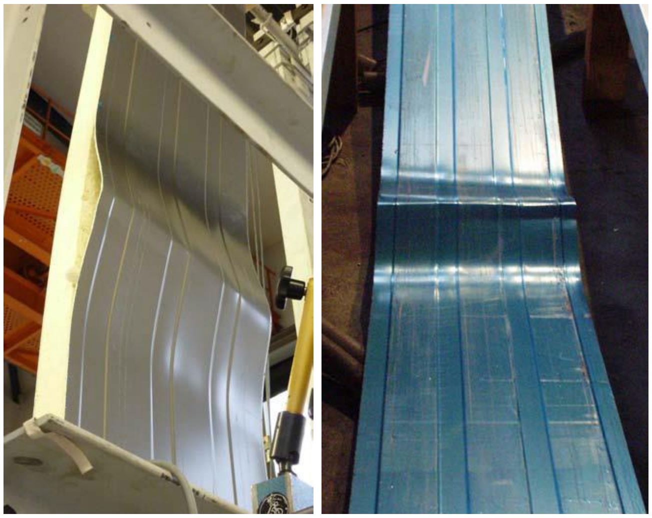


Figure 4a Wrinkling of the compressed face (EASIE 2011)

Figure 4b Shear failure of the core (EASIE 2011)

2.2.3 Environmental Design Considerations

The lightweight sandwich panel considered in this study is required for refrigerated purposes. This poses a different challenge, especially when considering the fact that the surfaces will be exposed to two different environmental conditions and the fact that the linear expansion coefficients of constituent components are different. The environmental conditions are assumed to prevail throughout the whole year. In our assumption, a higher than average is considered for very warm climate while a constant indoor temperature of the cold store is taken as the requirement for frozen fish -30 ºC. When cold room are considered, the required operating temperature for the indoor and outdoor conditions is a factor that requires concern. For indoor temperature of -30 ºC and summer time operating temperature of +80 ºC. (Davies 2001)

3 COLD AND REFRIGERATED WAREHOUSES

Traditionally cold stores and warehouses have been built with materials such as bricks, concrete and wood to which vapour barrier and insulation have been fitted internally. Modern construction is now incorporating the use of lightweight sandwich panels. (FAO 1994).

Lightweight sandwich panel fitted with automated transport system for moving goods in and out of the structure and a possible dimension even of 100m wide, 200m long and 40m would produce large deflection caused by variation in the linear expansion capacity of the constituent parts. The linear expansion caused by the temperature variation of the inner and outer environments of the structure cannot be avoided.

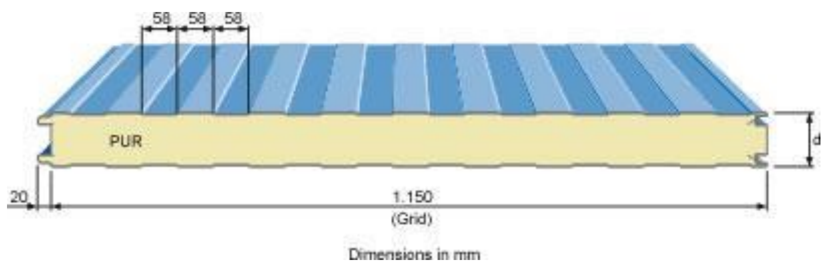


Figure 5a Sandwich panel

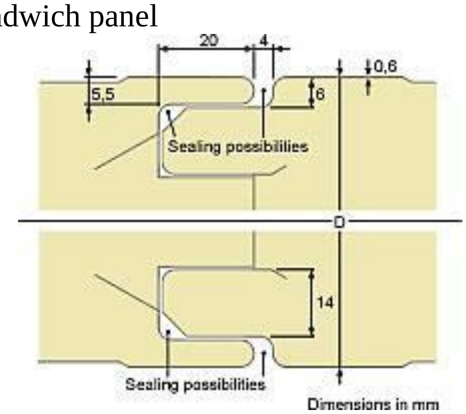


Figure 5b Joining the sandwich panel with sealing possibilities (sandwich construction)

3.1 Characteristics of Refrigerated Warehouses and Cold Rooms

Typical conventional cold houses have made use of reinforced concrete framework as the supporting elements incorporating concrete beams and columns. The disadvantages of this building construction when compared to a lightweight structure are a longer time of construction, bulkiness when weight is considered, and a higher heat exchange and losses. Lightweight sandwich construction results in a very tight structure which prevents excessive heat exchanges and thereby reduces the contact of hot and cold air. The use of a lightweight sandwich panel as a cold room structure results in minimized cold bridges. The figure 6 below shows roof to wall connection of sip sandwich panel

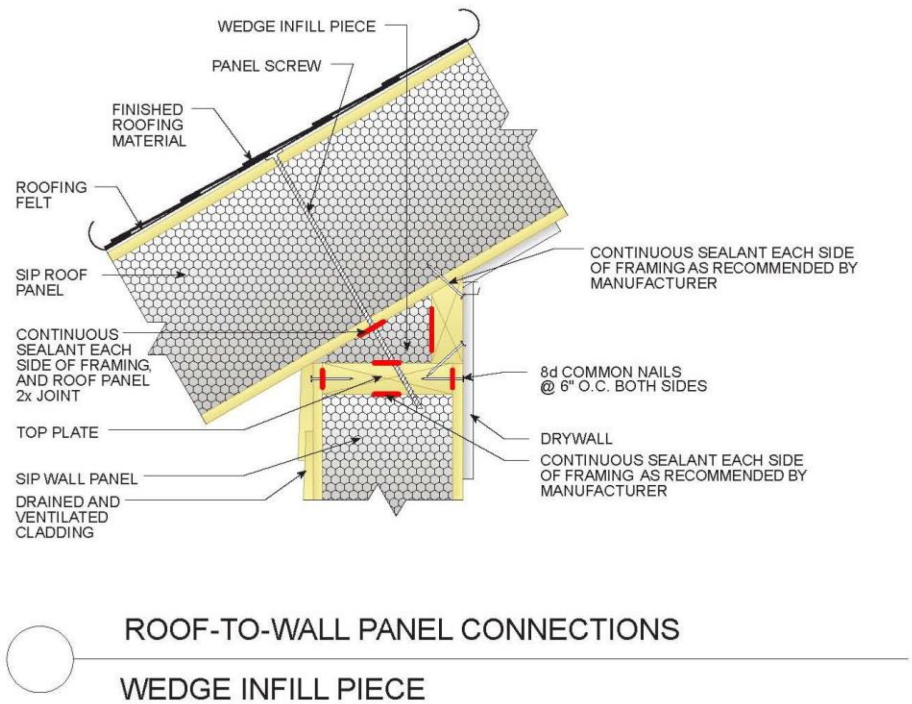


Figure 6 Roof and wall connection (sandwich construction)

Cold warehouses must incorporate a good and efficient insulation system, so as to enhance energy efficiency and reduce heat exchange. Cold air distribution within the unit must be efficient and this is usually achieved by heat exchangers; the natural convection coils and the forced-air cooler.

Refrigerated rooms usually have an internal temperature in the range of + 1ºC to +8 ºC, a cold room on the other hand, is designed to accommodate temperatures of between -18 ºC and -30 ºC. To obtain a satisfactory performance of refrigerated warehouses and cold rooms, the following conditions must hold and this characteristic is typical of all cold rooms. (Davies 2001)

- A very good insulation construction; this is very important as it accounts for a large proportion of the total construction cost, and to achieve a tolerable level of maintenance cost, the choice of insulation must not only meet the thermal conductivity requirement, it must also be odour-free, impermeable to water vapour, anti-rot and both vermin and fire-resistant. Insulation thickness is paramount to the efficient running of the cold room, and the selection of the right insulation thickness is governed by a number of factors which include the external and internal temperature of the structure, the selected core material in the panel, the energy and building cost and the design of the cooling system. To minimize the amount of incidence of solar radiation on the cold room, existing typical cold rooms are located inside cool buildings

- U-value referred to as the thermal conductivity is a term used to describe the amount of heat loss that occurs through an element of construction such as a wall or window. It is the thermal transmittance of material or a group of materials. It is also referred to as the 'overall heat transfer coefficient' and measures how well a building transfers heat. The lower the U-value the less energy is lost and the better is its insulating characteristic: a wall with a U-value of 0.3 W/m^2K is twice as well insulated as a wall with a U- value of 0.6 W/m^2K. U-values allow regulators to set values which are neither material nor system specific but can be achieved by different combinations. The EUROCODE, EN 1991-1-5-thermal action has a requirement for U-values which is contained in the national annexes of the different countries that have enacted their acceptance of the EUROCODE. U-values are also a first guide for designers and architects in setting the thermal performance of the building envelope. Therefore, U-values for building components are important parameters in the design process. However, due to increased energy costs, FAO (1994) recommends a U-value of $0.17W/m^2K$ for construction intended for cold stores and refrigerated warehouses, although higher values have been used in such construction.

- Air-tight and moisture-tight construction: this helps to prevent the accumulation of water vapour which condenses to form frost or ice. Refrigerated warehouses and cold rooms must be protected from such build up. In addition to the increase in air tightness and decrease in thermal bridges screws at the joints should be insulated and additionally be made of materials which have the same mechanical and chemical properties as the adjoining connecting materials. This reduces the thermal bridge effect and corrosion; it also prevents high difference in thermal expansion caused by difference in material. In the figure 7 below joints and connecting parts are adequately configures to ensure air tightness and to prevent accumulation of water vapour.

3.2 Sandwich Panels in Cold Warehouses

As the name suggests lightweight panels indicates that the structure should be lightly weighted compared to the traditional cold room structures. This is achieved by the use of light weighted components such as thin metal sheeting materials. The self-weight of a lightweight sandwich panel is relatively very low and it is in the range of 10-25Kg/m^2. This self-weight is a permanent load and in addition to the weights of other structural components that are supported by the panels. The important load case for sandwich panels is caused by the difference in temperature; while the external temperature varies during the day, the internal temperature of the structure is designed to be fairly constant. However, the advantages of light weight sandwich panels in cold rooms over the traditional cold room structures are its ease of construction and fabrication, the lightness in weight which facilitates easy transport and installations and tightness thereby preventing the build-up of frost and cold bridge effects.

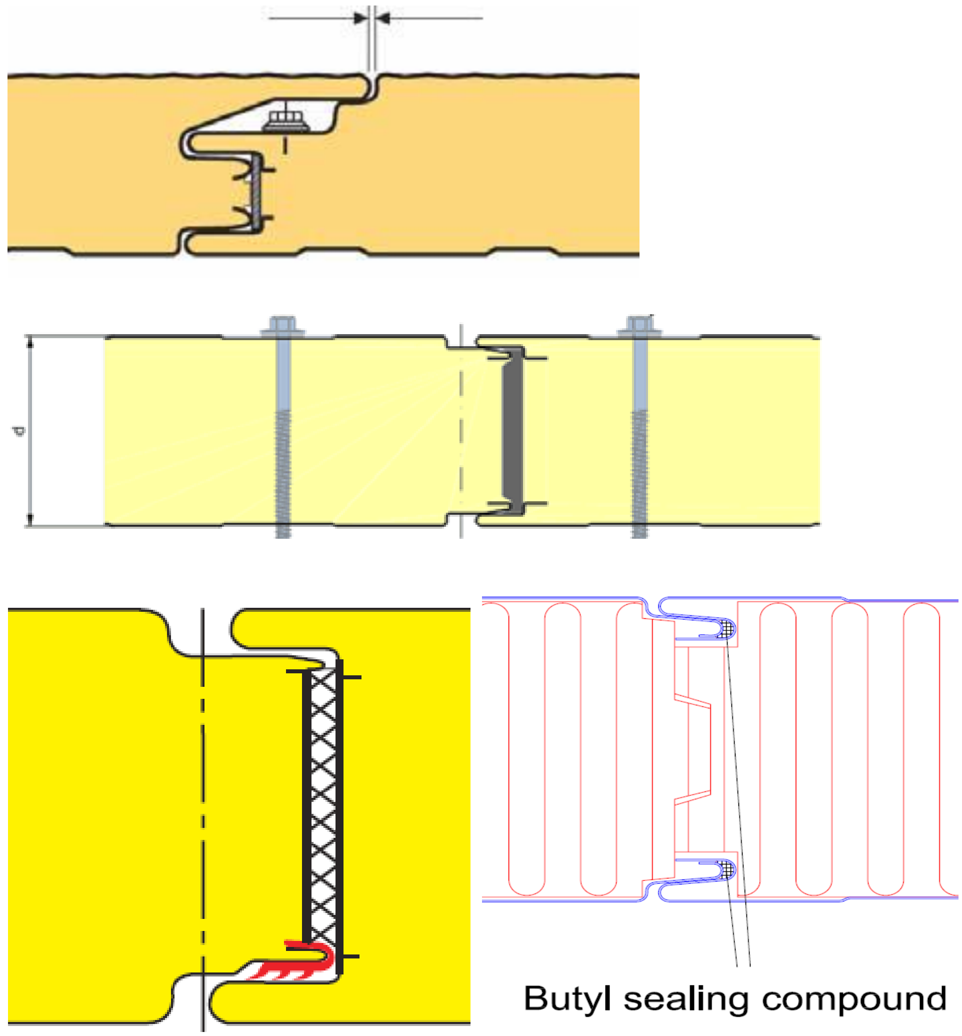


Figure 7 Sandwich wall panel and possible joint connections showing concealed and unconcealed screw connection and sealant (EASIE 2010)

Ruukki is a metal expert company, with a product range from components and systems to total solutions. Ruukki SP2E PU sandwich panel with rigid polyurethane core is intended for refrigerated warehouse construction. The product is designed for both the roof and wall systems. Appendix 1 shows Ruukki SP2E PU product specification, general information, detailed information and description. It also includes the installation instructions of the products.

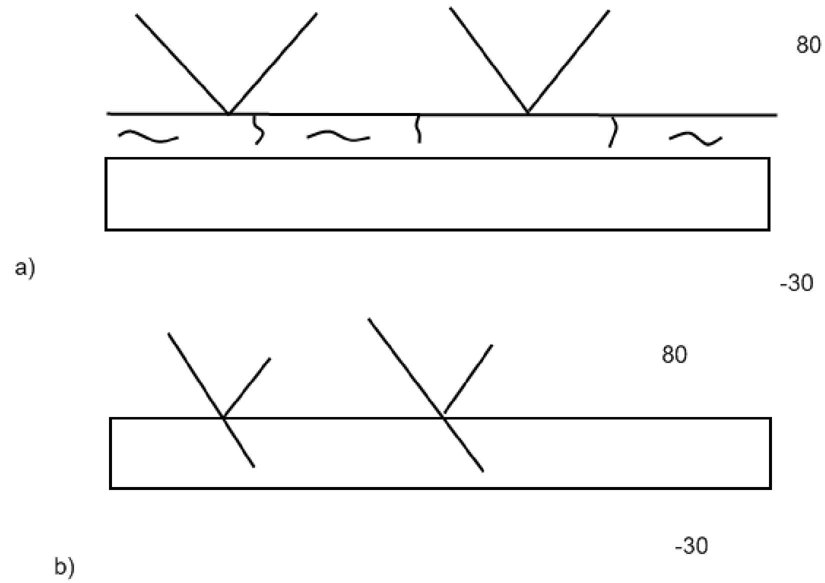
4 THERMAL LOADS IN SANDWICH PANEL STRUCTURES

The aim of this study is to minimize the effect of the thermal load on lightweight sandwich structure use in refrigerated warehouses and cold rooms. Since sandwich structure enhances an airtight structure, thermal bridge and

the openings and closing of the structure during operational use must be a key consideration to enhance this air tightness. The effect of temperature gradient cannot be neglected; part of the sandwich panel failure is dependent on this. The main load associated with thermal heating on a sandwich panel is the environmental incidence of solar radiation of the sun.
For a surface to stay cool, it needs two attributes; reflectivity and emissivity (Solar reflectance index 2008) While reflectivity and emissivity are associated with and controlled by the panel faces, their effect transcend beyond the faces of the panels and even to the core material which is being protected by the faces.

Thermal loading on sandwich panels has been reported in early experiments to have some structural and damaging effects on the faces of the panels, as well as on the screws and connections thereby reducing the resistance of the structure and exposing it to the subsequent failure. In this study, thermal loading on lightweight sandwich panels is restricted to the effect of solar radiation which in most hot climate reaches an average of over 45 ºC. CIB recommendation for the surface temperature of sandwich panels is as shown in Table 2 below.

In the Kingdom of Saudi Arabia an average of more than 5,500W/m^2 of global solar radiation per day on a horizontal surface is reported (Mohandes & Rehman 2012). The kingdom of Saudi Arabia is amongst the warmest regions of the world.



a = existing structural arrangement to reduce thermal load on a sandwich panel
b = penetration of radiant heat into sandwich panel

general arrangement with outside and inside temperature of 80 degree celcius and -30 degree celcius respectively

Figure 8(a) thermal heat reduction on sandwich panel. a) glass covering with air flow underneath the covering

Table 2 Design temperatures (^{0}C) for sandwich panels

	Serviceability limit state	Ultimate limit state
Summer (European conditions) • inside • inside, cold stores, etc. • outside ○ very light colour ○ light colour ○ dark colour	+ 25 Ambient operating temperature + 55 + 65 + 80	+ 25 Ambient operating temperature + 80 + 80 + 80
Winter (European conditions) • inside • inside (cold stores, etc.) • outside ○ maritime climate (UK) ○ Central Europe ○ Nordic countries • outside, simultaneous snow load on the roof	+ 20 Ambient operating temperature - 10 - 20 - 30 0	+ 20 Ambient operating temperature - 10 - 20 - 30 0

The incident radiation of the solar energy on any surface on the earth is determined by the amount of gas present in the atmosphere, the relative humidity and the geographical location. On the other hand, the amount of solar energy absorbed by a surface is dependent on the reflectivity, emissivity and absorption capacity of that particular surface.

Reflectivity measures how well a material bounces back radiation. But since all surfaces absorb some certain amount of solar radiation as heat energy, we also need to consider emissivity, or how good a surface is at radiating heat back out into space (Solar Reflectance Index 2008.) The heat absorbed is the heat emitted in a steady state.

Materials are classified as Blackbody, Greybody or non-Greybody, each classification is determined by the emissivity and reflectivity of the material.
A blackbody material is a perfect emitter of thermal energy and thus a poor reflector of heat and hence has an emissivity value of 1.0 (100%).

This explains why black surfaces are good absorbers of heat and poor reflectors while light coloured surfaces reflect more heat than they can absorb.

The “solar reflectance index” (SRI), defined by ASTM 1980, incorporates both reflectivity and emissivity. The combination of reflectivity and emissivity means that light-coloured polymeric membranes and coatings, which are good emitters of heat, tend to perform better than metallic surfaces, which can be more reflective but which heats up more because of its low emissivity. (Solar Reflectance Index 2008).

A sandwich panel which is to be designed for use as a refrigerated warehouse must incorporate light-coloured polymeric membranes and coating on all surfaces exposed to solar radiation: this will enable optimum and adequate reflectivity and emissivity, hence this minimizes the absorption of least amount of heat energy incidence on the surface.

Polymeric membranes are micro porous films which act as semi-permeable barriers to separate two different media, and are made of specially formulated polyethersulfone (PES) or polyvinylidene difluoride (PVDF). They can also be formulated as paint coatings for both indoor and outdoor uses. While different polymeric membranes have excellent advantages, they pose some restrictions in their use especially when energy saving is a consideration.
Polyethersulfone is known to have excellent mechanical and chemical properties. However, it is restricted from outdoors because of its poor weathering resistance. This makes polyvinylidene difluoride (PVDF) a better choice as paints in outdoor application.

In addition, some factors also affect the level of thermal loads on sandwich structure, and these factors have a direct relationship on the structural design and positioning of the structure (face sheets).

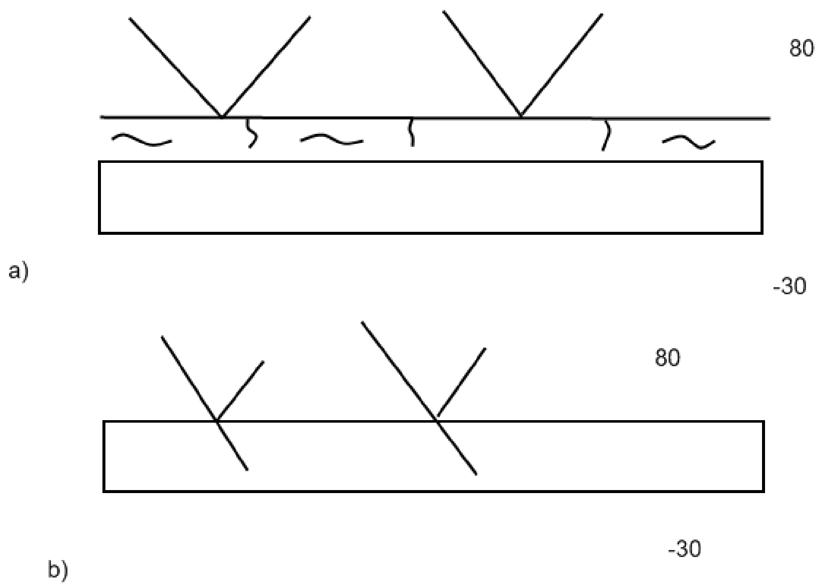
- the smoothness of the face sheet (polymeric coating surface and coating material)
- inclination of the sandwich surface
- the geographical location of the structure
- the thermal expansion coefficient* of the materials within the panels and which are affected by the temperature gradient
- the type and nature of core material; the U value and the insulating capacity

*The expansion and contraction of material must be considered when designing large structures, when large changes in dimensions due to temperature are expected. All materials have different thermal expansion properties (Table 3). The thermal expansion coefficient measures how well a material increases in dimension when there is a change in temperature. For a composite structure like a sandwich panel, each constituent component expands and contracts for every increase and decrease in temperature. This mismatch, on a microscopic level, introduces large stresses in the composite structure due to the thermal expansion of the constituent component.

Table 3 Coefficient of thermal expansion of materials

Coefficient of Thermal Expansion of different Materials (K^{-1})			
Name of Material		Coefficient of Temperature Expansion	
Material	Coefficient of Expansion in inches of expansion per inch of material per degree F.	Material	Coefficient of Expansion in inches of expansion per inch of material per degree F.
ABS plastic	0.0000170 (glass fiber-reinforced)	Acrylic	0.0001300 (extruded)
ABS plastics	0.0000410	Polyethylene	0.0001110
Aluminum	0.0000123 - 0.0000129	Polycarbonates	0.0000440
		Acrylic	0.0000410 (sheet cast)
Brass	0.0000104 - 190	Epoxy	0.0000310
Brick	0.0000031 (brick masonry)	Ice	0.0000280 (effects of freezing water)
Cast iron	0.0000058	Zinc	0.0000165
Cement	0.0000060	Lead	0.0000151
Clay tile	0.0000033	Aluminum	0.0000123 - 0.0000129
Concrete	0.0000080 (Concrete structure = 0.0000055)	Brass	0.0000104 – 190
Copper	0.0000093	Clay tile	0.0000033
Epoxy	0.0000310	Mortar	0.0000041 - 0.0000075
Glass, hard	0.0000033	Iron, pure	0.0000067
Glass, plate	0.0000050	Steel	0.0000063 - 0.0000073 (also Iron, forged)
Glass, Pyrex	0.0000022	Cast iron	0.0000060 (gray cast iron)
Granite	0.0000044 (also Limestone, Marble)	Cement	0.0000060
Ice	0.0000280 (effects of freezing water)	Nylon	0.0000447 (molding & extruding compound)
Lead	0.0000151	Glass, plate	0.0000050

To reduce the effects of the solar heat on the sandwich structure, some structural solutions are used in the construction and design of such panels. Figures 8(a) and 8(b) show structural arrangements that help to reflect heat away from the sandwich surface and thereby reduce the amount of heat emission by the structure.



a = existing structural arrangement to reduce thermal load on a sandwich panel
b = penetration of radiant heat into sandwich panel

general arrangement with outside and inside temperature of 80 degree celcius and -30 degree celcius respectively

Figure 8(b) Emission of thermal heat energy by the sandwich panel.

4.1 Thermal Loads on Panels

Sandwich panels are typically self-supporting roof and wall cladding panels in industrial and office buildings or in the constructions of cold storage houses and cooling chambers. The sandwich panels are usually loaded by permanent loads like self-weight and by variable loads like the wind and snow loads and in addition by the temperature difference between internal and external faces which produces the thermal action on the structure. These daily changes of the temperatures cause alternating repeated loads, thus subjecting the screw to a risk of a fatigue failure; bending moment in the shaft of the screw. Since this load is observed in the fastener between the sandwich panel and the support sub-structure, it is obvious that the resistance of the screw to the temperature movements increases with the thickness of the sandwich panel and decreases with the thickness of the substructure (Hassinen & Misiek 2009)

Earlier studies indicate that the effect of thermal action on a panel is also a function of the orientation of the supports on the panel (Blaszezuk J & Pozorski Z 2011.) Hence a one-span panel will be affected differently compared to a two-span or multi-span panel so also will the flat profiled and the deep profiled panels be affected differently even when subjected to the same load case (temperature and/or transverse).

Blaszezuk & Pozorski (2011) provide a useful finding on the behavior of single and multi-span sandwich panels under the action of temperature and transverse loads. Various failure modes for deep-profiled panels are shear failure of the core, shear failure of a profiled face layer, yielding of a face, wrinkling (local buckling) of a face, crushing of the core at a support, failure at the points of attachment to the supporting structure and the attainment of a specified deflection limit. In the case of flat multi-span panels it is observed that the local buckling is the most important.

The daily changes in temperature cause the panel to deflect as shown in Figure 10.

Basically we are looking at the Heat transfer from the radiant energy of the sun into the panel and the factors that affect the rate of heat energy flow.
For simplicity purposes, and if any calculation is made, calculation could be modeled after a single span panel, with a global heat energy of 5,500W/m^2 and internal and external temperature of panels of -30^{0}C and 80^{0}C respectively.

4.1.1 Effects of Thermal Loads

Sandwich panels are typically self-supporting roof structures and wall claddings, they are basically loaded by permanent loads; self-weight, and variable loads; wind and snow load. In addition, the temperature difference between the internal and external faces introduces an additional load on the structure which finds its effect on the connections, joints, and as well as the faces.

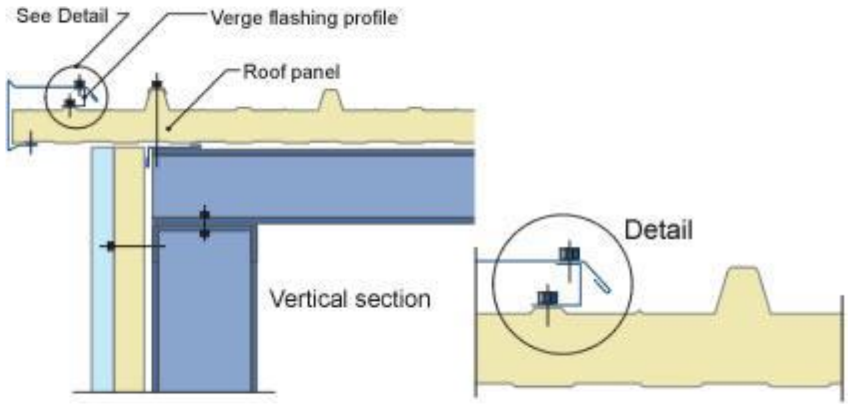


Figure 9 Roof and wall connection (sandwich panel construction)

As solar radiation is incidence on the external face of the panel, it causes the temperature to increase, thus inducing a thermal loading effect and temperature gradient on the structure. Since the internal and external temperatures are different, the effect of this difference causes the outer panel surface to expand (deflect) and consequently causes stresses on the joints and shear stress on the core material. Figures A and B.
In addition, this difference in temperature results in a relative displacement of the faces, thus producing a bending moment in the shaft of the screws. These constant and daily changes in temperature cause the alternating repeated loads on the screws, thus subjecting the screws to a risk of fatigue.

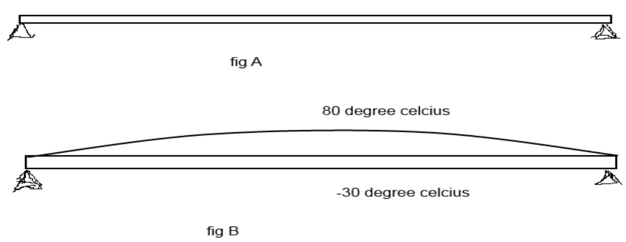


Figure 10 Single span sandwich beams under thermal action (deflection)

Since the intensity of the thermal load on the faces or structure depends on a number of factors, this infers that every exposed part of the sandwich panel receives different intensity of heat; the thermal load on a horizontal surface is never the same as that on an inclined surface even if the geographical location of both surfaces is the same and both are under the same intensity of solar radiation.

Thus, the thermal load on the roof which is a near horizontal orientation is never the same as the thermal load on the wall surface of the structure.

Structural effects caused by thermal loading on a lightweight sandwich panel

- Thermal Buckling of outer face sheet/high deflection of span
- Sandwich-core interfacial shear stresses
- Normal stress in the face sheets
- Wrinkling of sheet
- Stress on the joints and fasteners due to expansion caused by temperature difference
- Bending of the sandwich beam

William M. & Raymond H. (1991) in their thermal stress analyses of a sandwich panel core conclude that the effect of interfacial shear stress caused by the thermal loading due to temperature gradient is relatively low and would not cause de-bonding between the face sheets and the core. They also conclude that the buckling effect is negligible.
No matter how negligible these effects have on the structure, and because the loading is continuous and not instantaneous it still has to be considered in the overall design of the structure and thereby minimizes the effects.

It should be noted that the above effects caused by the temperature gradient in a sandwich panel are all related and as such dealing with one effect automatically affects the other effects. The overall effects are caused mainly by the temperature gradients.

The temperature difference between the internal and external faces triggers a curvature of the faces hence deflection on the single span panel. This is shown in Figures 3a, and 10.

Nevertheless, the influence of the thermal heat from the sun produces a thermal load, and hence temperature difference $\Delta T = T2 - T1$ between the internal and external faces. This triggers this initial curvature hence thermal load θ on the faces. For a simply supported structure, (Figure 10) thermal excitation results in an initial constant curvature θ (Figure 9)

$$\theta = (\alpha_1 T_2 - \alpha_2 T_1)/ e$$

Where α_1, α_2 are thermal expansion coefficients of the respective faces, e is the distance between the centroids and the faces.

For a single-span panel with flat faces of same thickness D and material, this temperature gradient results only in displacements, i.e (maximum deflection) given as $\theta L^2/8$

L is the span of the panel

Consider a sandwich panel with outside and inside temperature of 80 ºC and -30 ºC.

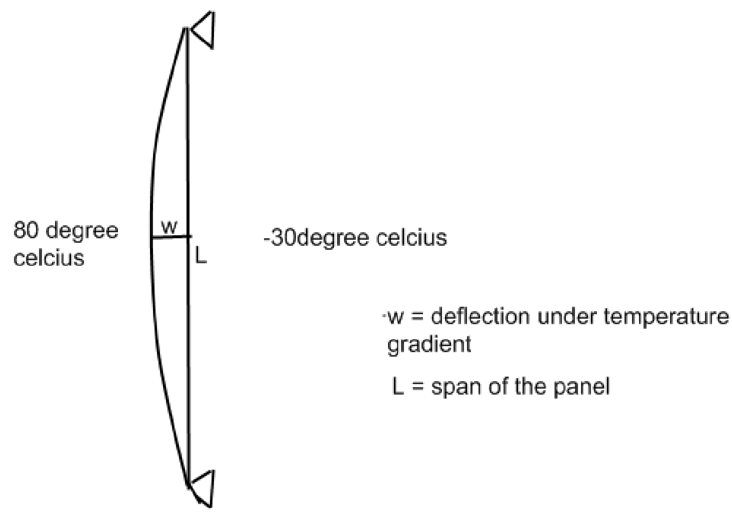


Figure 10a Wall panel under deflection by temperature gradient.

$\Delta T = T2 - T1$
$= 80^0C - (-30^0C) = 110^0C$
$\alpha 1 = \alpha 2$; *thermal expansion coefficient*
$\alpha 1 = \alpha 2 = 12x10^{-6} K^{-1}$
$L = 5000mm$
$D = e =$ *distance of centroid of faces* $= 100mm$

$$\theta = (\alpha_1 T_2 - \alpha_2 T_1)/ e$$

$$w = \theta L^2/8$$

$$w = (\alpha_1 T_2 - \alpha_2 T_1)L^2/ 8e$$

$= \Delta T.\ \alpha 1.\ L^2 / 8e$

$= 110\ K \times 12 \times 10^{-6}\ K^{-1} \times 5000^2\ mm^2 / 8 \times 100mm$

Maximum Deflection $= 41.3mm$

4.1.2 Thermal Loads and Reduction of Heat Losses

Heat transfer, loss and exchange can occur through a structure in three distinct processes: conduction, convection and radiation. Convection is a transport of heat energy in air that flows through the structure, this amount to a significant high amount of heat exchange in any structure. Radiation accounts for a very little heat transfer across the structure but rather occur on the exterior surface of the structure in the form of solar heat energy transfer. Because this study is concerned with the effects of solar heat load on the structure (sandwich panel) much of the solution is aimed to minimize the solar heat loads on the structure. Conduction on the other hand, is the flow of heat through materials in direct contact and it is responsible for the majority of heat flow in structures.

Since a sandwich structure is composite in construction, thermal bridging is a major component by which heat is exchanged within and outside the structure. Thermal bridging results in the loss of energy through conduction; thermal bridging is the loss of building heat energy through conductivity of elements with a relatively higher thermal conductivity that penetrates into and across the insulation of a wall or roof enclosure of a conditioned space when there is the existence of temperature gradient.

Radiation is also a process through which heat energy from the sun can also be transferred into the structure, thereby altering with the temperature equilibrium of the entire structure. To maintain a constant internal temperature of the cold warehouse, it is practical to provide measures that could reduce the incidence radiation of the sun from unnecessary increase of the outer surface temperature of the sandwich panel.

4.1.3 Solution to Thermal Bridging

Thermal bridging in a structure poses two main consequences, firstly, local heat losses occur which suggest requiring more energy to maintain the internal temperature of the structure, and secondly, there is a lower internal temperature around the thermal bridge which can cause condensation leading to the growth of mould. Thermal bridging in refrigeration and cold warehouse structures can be caused by corners with additional heat flow paths, windows sills and door openings, floor to wall joints, others are caused by fixings and structural elements, gaps in insulation and debris in a wall cavity.

A number of measures are presently used to help to minimize the effects of thermal bridge on building envelops. Steel has a higher thermal conductivity than other construction materials and as a result it is being prevented from gaining consideration penetration through composite (sandwich) cladding.

A thermal break is another measure to ensure the reduction of thermal bridging in structure particularly in sandwich construction. Here, steel members may be connected by ensuring that a low thermal conductivity material is placed between the steel members, this low thermal conductivity material usually forms the insulating medium. This is shown in Figure 11 belowFig.11

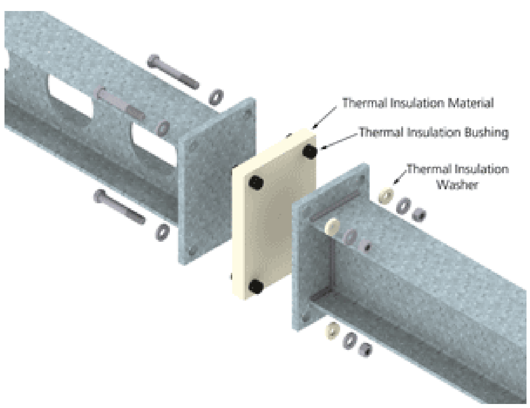


Figure 11 Thermal breaks in structural steel members (Fabreeka vibration)

In the event of joining and connecting, screws with a high thermal conductivity should not be connected directly through the composite elements of the sandwich structure (Figure 7): this kind of arrangement prevents a thermal break. In addition, adequate sealing tapes and/or Butyl sealing compound should be used to seal off joints (Figure 7). When panel screws are made to connect the entire elements of the structure, they should be made of a low thermal conductivity material (ceramic) or insulated and concealed from the outside temperature.

High temperature resistant ceramic screws and fasteners are gaining grounds and popularity as connection parts, they come in different sizes and dimensions; they can offer a good solution as a thermal break in sandwich connections of adjoining components. It could also offer a cost effective solution to replace stainless steel screws which are relatively more expensive.

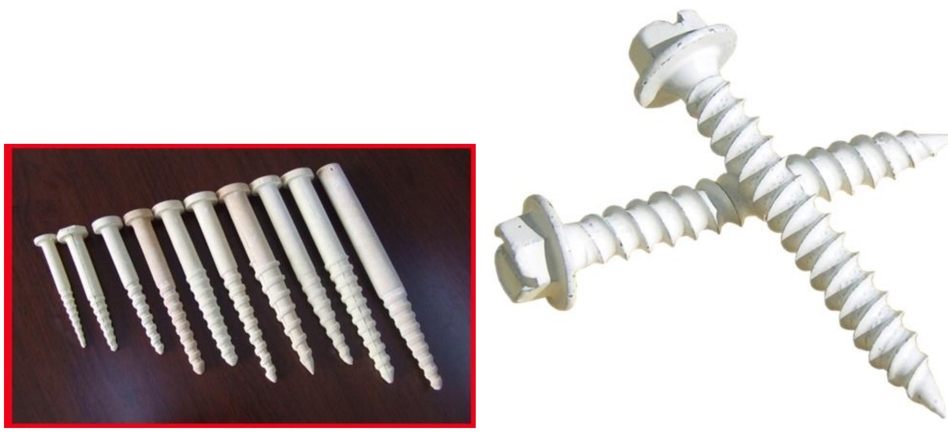


Figure 11a Ceramic screws

4.1.4 Structural Arrangement and Solution

Some existing structural arrangements which help to reduce the effect of the thermal loading on a sandwich panel have been documented Figure 12a represents one such arrangement. In Figure 12a, glass cover is mounted over the sandwich panel, with a free space for air flow underneath, the air further cools the escaped heat from the glass cover.
Another existing structural arrangement which has also been documented is the housing of the entire sandwich structure inside a concrete shade to prevent solar radiation from reaching it. This is not cost effective; it is more expensive since the concrete shade adds bulkiness and additional cost in the overall cost of the entire structure. Figure 12c

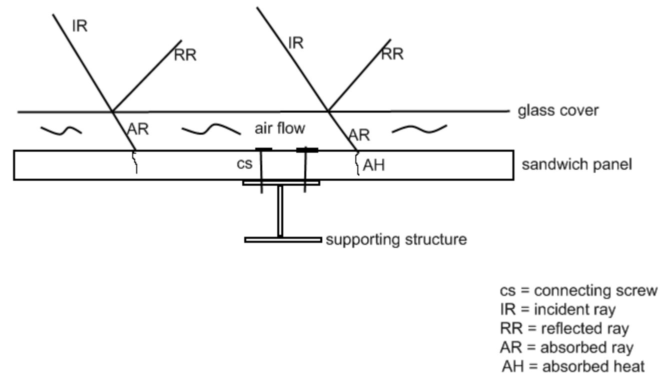


Figure 12a Existing arrangement to reduce thermal load (Davies 2001).

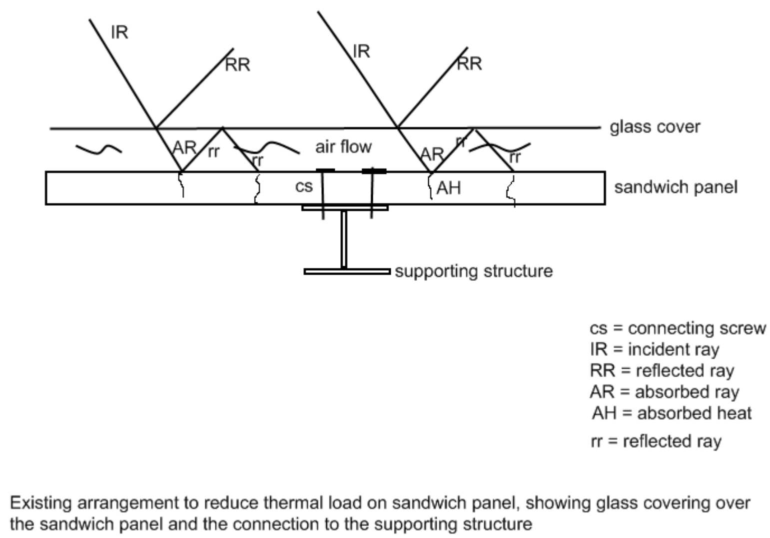


Figure 12b Existing arrangement to reduce thermal load on sandwich panel (Davies 2001)

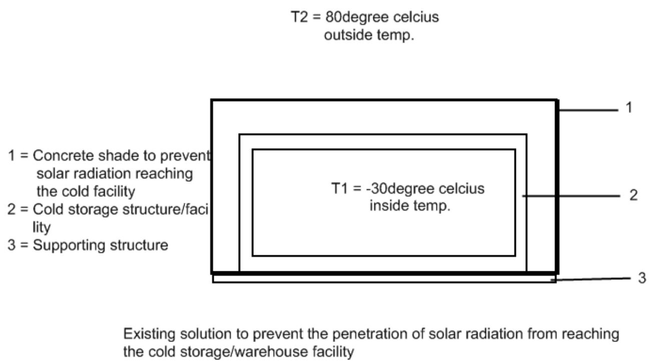


Figure 12c Existing structural arrangement to reduce solar rays on cold storage; cold storage facility built inside a concrete shade.

Figure 12b shows the drawback of the existing arrangement, glass is transparent in nature, it allows light and rays to pass through. This allows rays to pass through and fall on the panel, as the escaped incident ray hits the sandwich panel. Part of it is absorbed and part is further reflected from the sandwich panel. It then hits the glass cover and it is further reflected back onto the panel to be re-absorbed. The repeated reflection and re-absorption on a minute level maintains heat energy on the panel surface, although the air flow in the space beneath the cover helps to cool down this heat. The heat reflected and absorbed or re-absorbed could not be calculated in this study as it is beyond its scope.

To modify and improve the existing arrangement, this study proposes two alternative measures: both still utilize the covering over the panel but with different material:

The first option is the use of glass cover over the sandwich panel with a white paint coating of PVDF as the polymeric membrane. PVDF base-coating if mixed with an appropriate chemical and gluing agent to improve its gloss quality can also act as an excellent adhesive base coat on the glass. Directly on top of the sandwich panel is polyurethane insulation which is glued onto the panel. Air space is allowed to maintain a free air flow. To attach the glass cover on the panel, it is first pre-drilled and screwed to the panel at the support. Ceramic self-drilling screws could also be used to connect the glass on the panel (Figure 13ab)

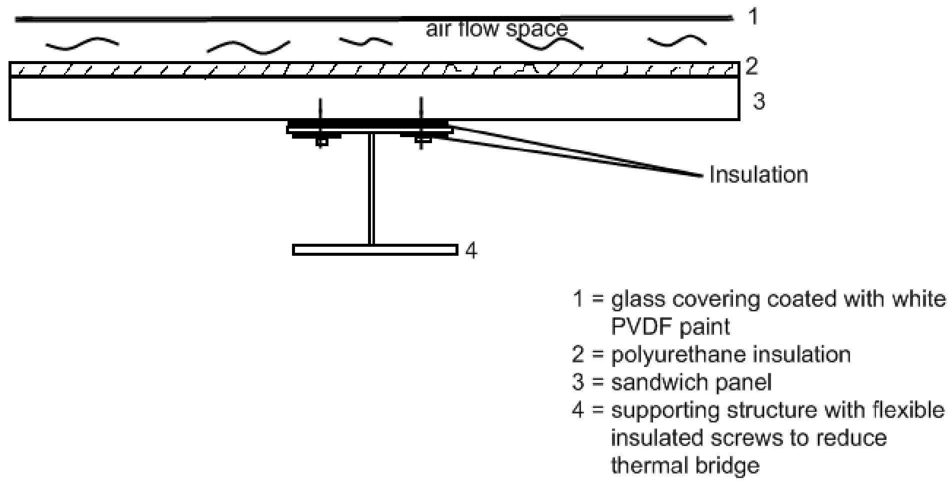


Figure 13 structural arrangement showing glass cover coated with white PVDF paint

Polyvinylidene difluoride PVDF coating has ideal combination of characteristics: good formability, endurance to UV and heat, good resistance to corrosion, and rarely chalks. Its highest operating temperature is 120 degree Celsius which makes it suitable for warm climates. However, it’s expensive which makes it not a cheap option when cost is a deciding factor.

Polyurethane insulation has weathering and UV resistance quality which makes it an outdoor choice for the arrangement. Because UV radiation eventually wears paints and materials that are in direct exposure, periodic maintenance and replacement of these materials is recommended to enhance long service life of the arrangement. Figure 13

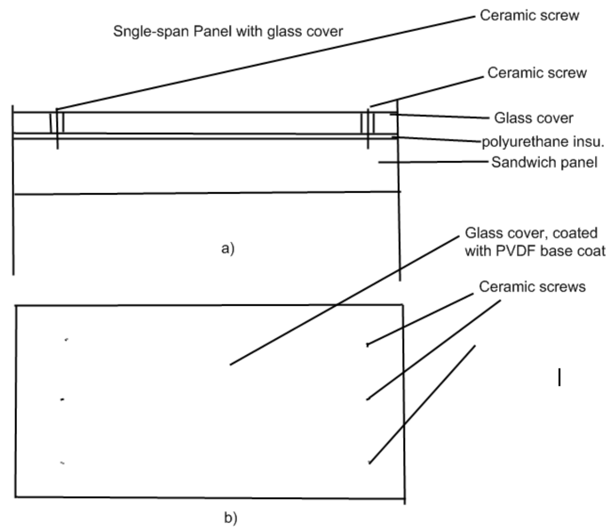


Figure 13ab screw connection of the glass cover on the panel

Option two;

Aluminum has excellent mechanical and chemical properties, its shiny appearance acts as a good reflector of heat and hence minimizes the emission of heat energy. Because it appears to be nobler than most metals, it can react less with atmospheric chemicals and thus requires no paint coating. However, its use can be restricted to non-coastal and industrial areas because of the presence of chemicals and salts which readily attach the metal.

A lightly profiled thin sheet of aluminum is used as a cover over the sandwich panel. Profiled aluminum is preferred over a flat sheet in order to enhance stiffness and increase its load carrying capacity (Figure 14). It is mounted on the structure with the aid of support connected to the panel by insulated self-drilling screws to reduce the thermal bridge.

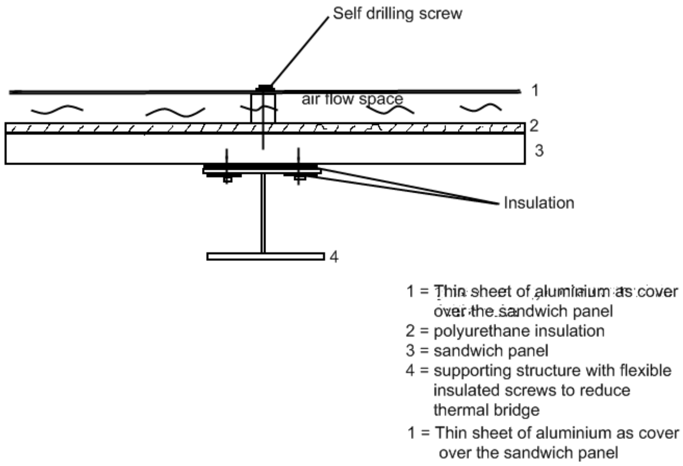


Figure 14 structural arrangement showing aluminum cover and support.

5 CONCLUSION

The study established that the thermal load on sandwich panels designed for a cold storage facility is caused by the incident radiation of the sun; the sun's UV radiation causes heating and thus produces temperature gradient between the internal and external environment of the facility.

The effect of the thermal load on a sandwich panel is seen to vary depending on the nature and the facial orientation of the sandwich panel; for one span panel with a flat face, the thermal load results only in displacement hence a maximum deflection in the span. For multi-span and deep-profiled faces, the effect results in intermediate stresses, bending moment and shear forces in the structure.

Existing structural arrangement geared to reduce the effect of this thermal load on lightweight sandwich construction for refrigerated warehouses and cold store facilities has been criticised and modified in this study. A modified structural arrangement which incorporates additional insulation, glass or aluminium cover and polymeric paints was presented and recommended. The modified structural arrangement does not offer a complete reduction in the overall heat energy that reaches the face of the panel. But it can be argued to be more effective in reducing the absorbed heat compared to the existing arrangement. However, to know how much heat is reduced by the arrangement would require experimental investigation.

Nonetheless, to standardize reduction criteria of thermal heat on panels would harmonize the design and manufacturing of sandwich panels intended for cold stores and refrigerated warehouses to a more stringent task thereby making the manufacturing of such sandwich panels to be both efficient and standardized: This is particularly necessary for panels intended for use in tropical regions since it considers high enough temperature gradient.

Since the structural arrangement does not maintain an efficiency of 100% it follows that some degree of heat is transferred onto the sandwich panel in the process, so also is heat loss from the internal environment of the warehouse. However, this amount of heat energy that escaped onto the sandwich panel could not be calculated in this study since it is not within the scope of this work.

In addition, the ceramic screw connector is introduced in this study as a means to check its viability as connecting component in construction, although no extensive empirical data is known about its mechanical and/or chemical properties. Manufacturers are of the opinion that it could serve the same purpose and also be as effective as the conventional stainless screw connectors. This could also be a necessary area of study to be investigated

In conclusion, with the recommended and proposed structural arrangement, further study is necessary to investigate how much heat passes onto the sandwich panel which would enable the investigation of the efficiency of the structural arrangement. This, in other words, would encourage further study and continuation of this work.

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