Steel Buildings with Low Annual Energy Consumption

Bâtiments en acier à basse consommation annuelle d'énergie

Bauten in Stahl mit niedrigem Jahresenergieverbrauch

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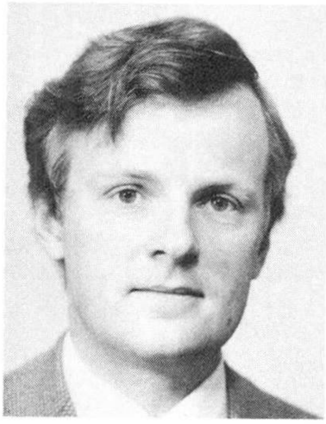

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SUMMARY
Energy efficient steel buildings with better thermal insulation to reduce transmission losses are now being built in Sweden. Examples of structural design are given to minimize the influence of thermal bridges. A method for the calculation of such heat losses ist presented. Principles for airtightness to reduce air leakage of buildings are discussed, special details and material requirements are given. A case study of such an energy efficient steel structure tennis hall shows that the heat loss from the lights will give an acceptable indoor air temperature for playing tennis during the Stockholm winter.

RÉSUMÉ
En Suède, on construit des bâtiments en acier «basse énergie» avec une meilleure isolation thermique pour réduire les pertes de chaleur par transmission. Des détails de construction diminuant l'influence des ponts thermiques sont décrits. Une méthode de calcul de ces pertes de chaleur est donnée. Des principes d'étanchéité à l'air visant à réduire les pertes par ventilation sont discutés, des détails spéciaux et des exigences de matériaux sont donnés. L'étude du cas d'une halle de tennis en acier montre que la chaleur fournie par l'éclairage suffit pour obtenir une température intérieure acceptable en hiver.

ZUSAMMENFASSUNG
In Schweden werden energiegerechte Bauten in Stahl mit besserer Wärmedämmung erstellt, um die Transmissionsverluste zu verringern. Konstruktionsbeispiele zur Minimierung des Einflusses von Wärmebrücken werden aufgezeigt. Eine Methode zur Berechnung solcher Wärmeverluste wird beschrieben. Grundsätze für die Luftdichtheit zur Reduktion der Lüftungsverluste werden diskutiert, spezielle Details und Materialanforderungen werden gegeben. Die Fallstudie einer Tennishalle in Stahl zeigt, dass die Energie der Beleuchtung im Winter genügt zur Erzielung annehmbarer Raumlufttemperaturen.

INTRODUCTION

The intention of this report is to shed light on the current question of the air-tightness and energy consumption of single storey industrial buildings, especially those constructed in steel and light gauge metal sheet.

It is a well known fact that steel is an excellent thermal conductor, its coefficient of thermal conductivity being in the order of 1000 times that of better types of thermal insulation. It is therefore necessary to avoid or substantially limit the use of steel members in thermally insulated walls and roofs. Steel studs bridging the interval and external surfaces of the wall or roof should be avoided at all costs. Mineral wool fibre with a low coefficient of thermal conductivity is the most commonly used material for thermal insulation. Mineral wool insulation is susceptible to the movement of air which requires the structure to have a satisfactory wind barrier and a high degree of air-tightness. It is, in reality, not possible to achieve satisfactory air-tightness with structural steel members and sheet cladding alone, the required air-tightness normally being achieved by means of a plastic sheet or, in the case of felt roofs, the roofing felt itself. In order to achieve a satisfactory degree of air-tightness, the air-tight membrane must be sealed at all joints and details, windows, doors etc. In order that the thermal insulation and the air-tightness of the building function properly it is therefore necessary that the construction and detailing of the building be well thought through and that work on site be correctly carried out.

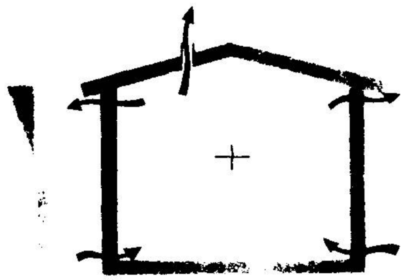
LIMIT AIR LEAKAGE

The following example shows the relationship between transmission losses and ventilation losses:

A small single storey industrial building, 18 x 24 m with a height of 5.5 m in the Stockholm region. The building is intended for use as a precision-tool workshop or the like, and is therefore heated to a temperature of 20^{0}C. The coefficient of thermal conductivity (k) is required by the Swedish Building Regulations to be 0.30 W/m^2 ^{0}C in the external walls and 0.20 W/m^2 ^{0}C in the roof. With the required k-values fullfilled, the thermal energy losses due to transmission are in the order or 43 MWh per annum. If the ventilation of the building including air leakage is assumed to be 0.5 air changes per hour then the consequential energy losses will be in the order of 45 MWh per annum. The transmission losses through the walls, roof and the windows are of the same order of magnitude as the ventilation losses.

If the building is constructed in such a way as to reduce the ventilation by 20%, or 0.1 air changes per hour, then this will result in a decrease in energy consumption of 9 MWh per annum. An acceptable level of air quality should be obtained even at the lower level of ventilation being as the volume of air inside the building is considerable when related to the number of persons present. In order to achieve the same reduction in energy consumption by improving the thermal insulation the K-value of the walls and the roof must be increased by 0.1 W/m^2 ^{0}C. The thermal insulation must be increased by 50-70 mm of mineral wool. This example shows that there are considerable savings in heating cost to be made by improving the air-tightness of the building. Improved air-tightness costs considerably less than an increase in thermal insulation for the same saving in energy consumption.

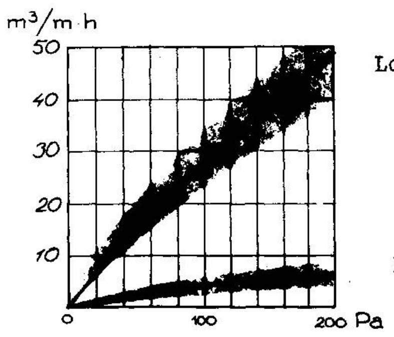
The governing force for air-leakage and ventilation in buildings is the difference in pressure of the air inside and outside the building. The forces affecting the air adjacent to and inside the building (excluding ventilation fans) and setting it in motion are wind and temperature. On a calm winters day the air pressure in the lower part of a building is lower inside the building than outside, and in the upper part of the building the air pressure on the inside is higher than that outside. The result is that cold air will seep in at floor level and that warm air will leak throught the upper walls and the roof, fig 1, giving rise to, apart from the increased energy consumption, uncomfortable draughts at floor level. Such draughts are unacceptable in a quality building. At roof level, and especially in the eaves area, warm air leaks out which, when cooled, may even give rise to condensation and moisture problems in the roof itself. In order to reduce the seepage of cold air at floor level and the leakage of warm air at roof level it is necessary that the climate shield of the building be air-tight.



Air pressure on a calm day
Air leakage
Cold outside - warm inside

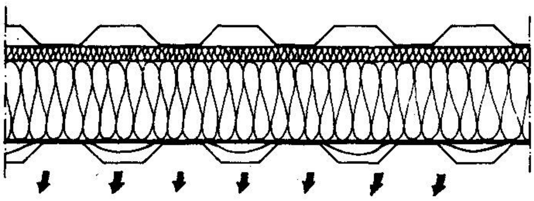
Fig 1 An insufficiently air-tight building where cold air seeps in at floor level and warm air leaks out at roof level due to thermal forces, wintertime. The prèssure gradient is for temperature related pressures on a calm day and fore evenly distributed air leakage.

The air-tight membrane in walls constructed with cold formed sheet steel studs and sheet steel cladding is a plastic sheet between the inside surface of the thermal insulation and the inside wall finish. This form of construction creates no problems on undisturbed walls. If the wall is punctured by vents, adjoining walls, joints, windows etc great care must be taken in the design of these details. For example where the bottom edge of the plastic sheet is free - when the plastic sheet is fixed in place with a profiled steel sheet - air will seep in easily if the inside air pressure is lower than that outside. If the air pressure inside is higher then that outside the plastic sheet is pressed against the ground plate, reducing air leakage. It is most common to find lower air pressure at floor level which makes it necessary to find a better method of construction to avoid the free edge of the plastic sheet which is found today. Figure 2.

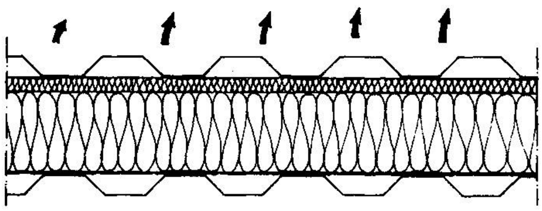


Lower pressure inside than outside

Higher pressure inside than outside.



Lower inside air pressure: the plastic sheet is pressed against the ground plate and against the thermal insulation.



Higher inside air pressure: the plastic sheet is pulled towards the profiled sheet wall causing leakage

Fig 2 If the plastic sheet is fixed to the ground plate only by means of a profiled steel sheet the air pressure at floor level will pull the sheet away from the ground plate and allow air leakage. If the air pressure is higher inside than outside the sheet will be pressed against the ground plate and reduce leakage. The latter case is however not the most usual one.

THE DESIGN OF DETAILS - EXAMPLES

There are several methods of ensuring good air-tightness in the ground plate detail, one of which is a sheet steel channel in which the plastic sheet is clamped by means of a plastic pipe as shown in fig 3. When tested, this detail gave 100 times less leakage than that of a free sheet edge. Another version of the same detail which also gives a low leakage value is to fasten the plastic sheet between a fixing strip and sealant as shown in fig 4. These details cost very little but are essential; the extra cost being very quickly repaid.

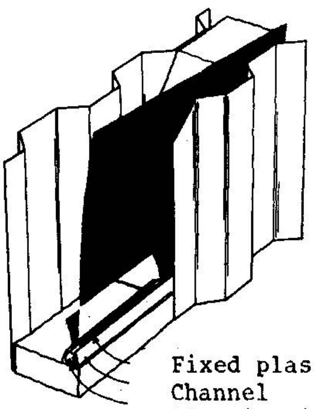


Fig 3 If the plastic sheet is fixed in a channel with a plastic pipe, electric conduit for example, excellent air tightness is achieved.

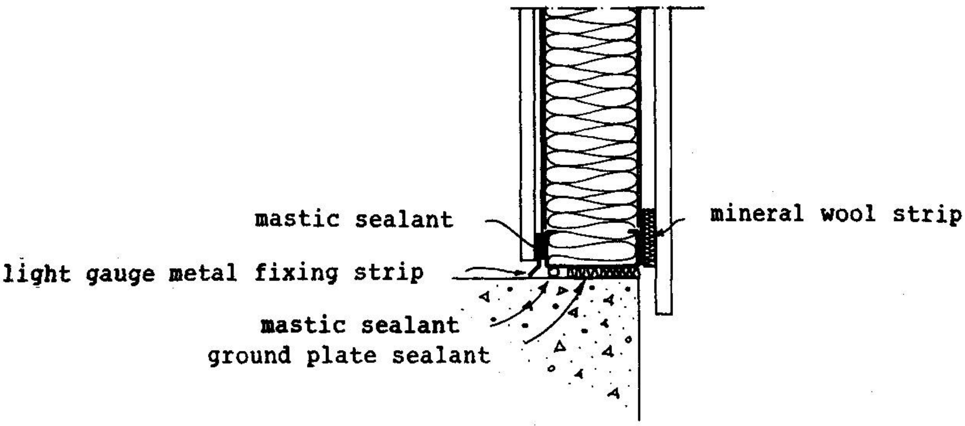


Fig 4 An alternative method of achieving good air-tightness in the ground plate detail is to fasten the plastic sheet with a special light gauge metal fixing strip. A mastic sealant or sealing strip placed between the plate and the sheet will ensure air-tightness. The joint between the ground-plate and the concrete foundation slab must be well sealed; mineral wool with a joint sealant on the inside gives an acceptable result.

There is normally some kind of special light gauge sheet steel eaves beam which causes the plastic sheet to be led round it in some way, usually on the outside. The internal exess air pressure presses the sheet away from the eaves beam creating a gap for leakage. This is an unsatisfactory detail which is simple to resolve. Here again all that is required is a light gauge metal fixing-strip which fixes the plastic sheet to the eaves beam, with a sealent between if necessary, as shown in fig 5. Again the cost per metre is very low. Minor adjustments in detailing can give greatly improved air tightness.

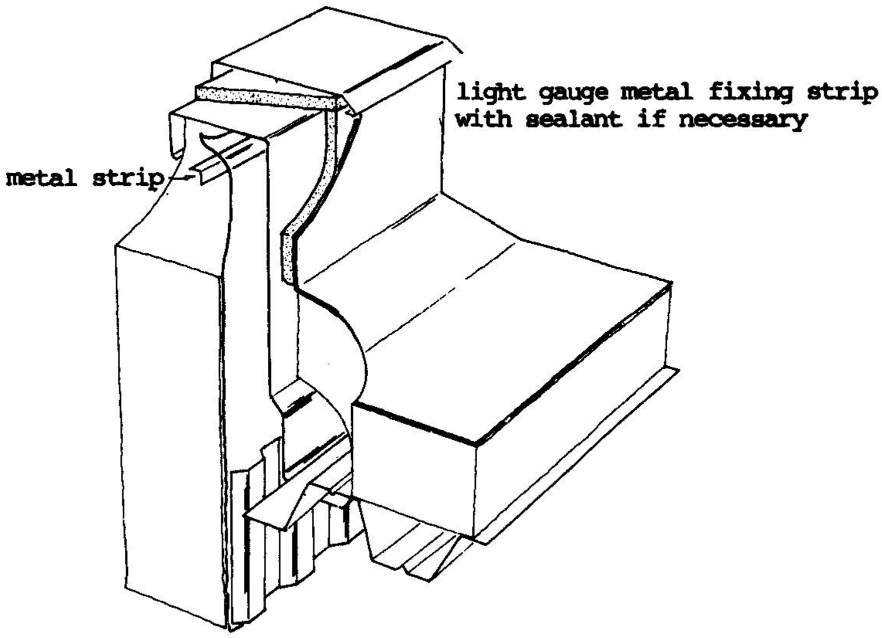
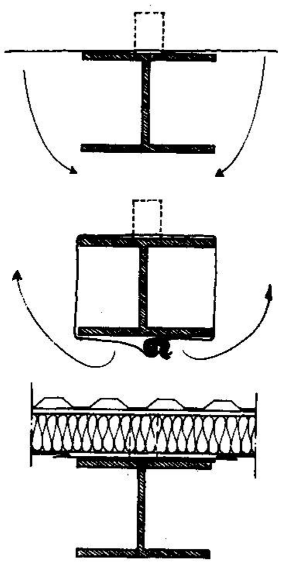


Fig 5 If the plastic sheet at the roof eaves is placed round the outside of the eaves beam there is a risk for air leakage being as the air pressure is often higher inside the building than outside. The sheet is drawn away from the beam and leakage occurs. The sheet must therefore be fixed with, for example, a fixing strip and mastic sealant in order to obtain sufficient air-tightness.

In thermally insulated sheet metal decked roofs where the surface material is roofing felt, there is often no plastic sheet on the inside. The roofing felt serves as a vapour barrier. The vapour barrier in the walls is however on the inside surface. It is therefore of great importance that the eaves detail is air-tight. One solution is to fix the plastic sheet to a piece of chipboard with the roofing felt glued to the reverse side. This solution is not an ideal one being as the chipboad is trapped between two air-tight barriers and may be susceptible to moisture damage. Better detail design is required here.

The eaves beam allows heat to be transferred from the inside of the building to the outside giving a loss of thermal energy which is used to melt snow and ice in the gutter and reduce the risk for an ice blockage. Thermal energy is intentionally released for an alternative perpose, which is not an ideal solution from the point of view of energy conservation. This detail should be improved. A reduced thickness of thermal insulation could be used with regard to the risk for freezing. The air-tightness of the detail must be observed.

The method of jointing the plastic sheet in the external walls is also of consequence to air-tightness. One method used which gives good joint tightness is to wrap a 0.5 m wide strip of plastic sheet round the column before the horizontal studs are fixed in place. Sealant is applied to the support details and the strip of sheet kept wrapped arround the column. When the plastic sheet in the wall has been fitted in place after the completion of the thermal insulation, the wrapped arround strip is folded out and sealed in the overlaps with a sealing strip as shown in fig 6. Overlapping edges in the plastic sheet without any form of sealing strip or the pressing together of the overlap will not give satisfactory air-tightness. This detail is not costly but does require thorough workmanship. The wrapped arround strip of sheet must be carefully fastened during construction to avoid wind damage.



Strip of sheet plastic fixed to inside of column during frame construction

The plastic strip is folded out and fixed in place using U-channels and plastic conduct

The plastic strip is folded out after the thermal insulation is pitted and the main plastic sheeting pitted and overlapped using a sealing strip

<u>Fig. 6</u> It can be difficult to place the plastic sheeting when steel columns are placed inside the facade. A strip of plastic sheeet is therefore fitted directly after the completion of the frame and carefully fastened so as to avoid wind damage during construction. When the thermal insulation and the plastic vapour barrier are in place the strip is folded out to give a good overlap joint with the main plastic sheet.

It is of great importance from the point of view of air-tightness that the air-tight membrane is not punctured by ducts, electric conduit etc. Improved detailing and instruction is required here. It is of great importance that all services are planned in detail while the building is still on the drawing board and that ducts are avoided as fas as possible. Fig 7 shows an example of a window-wall detail. Note the thermal insulation and the positioning of the air-tight sealant against the air-tight sheet in the wall.

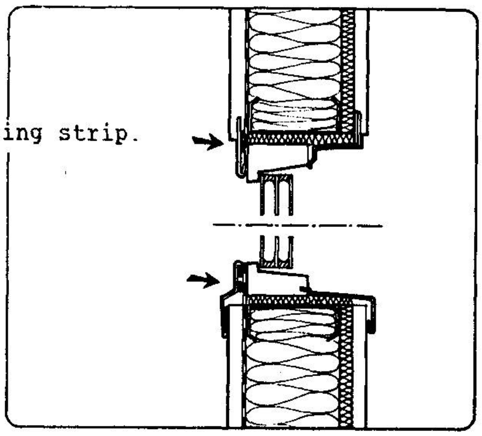


Fig 7 Window detailing. The plastic sheet in the wall is drawn over the window frame and fastened with a special sealing strip. An EPDM synthetic rubber sealing strip between the plastic sheet and the window frame considerably reduces the risk for air-leakage.

REDUCE THE EFFECT OF THERMAL BRIDGES

When a section of thermal insulation is breached by a material with a high coefficient of thermal conductivity a thermal bridge is created. Examples of such materials are steel, concrete or wood, the most disadvantageous of which is steel, due to its very high thermal conductivity properties.

A thermal bridge may cause several negative consequences such as:

- increased heating losses
- surface condensation
- soiling

Structures with severe thermal bridges give rise to high heating losses, that is to say they have a high mean k-value. Steel studs instead of timber studs in a structure insulated with mineral wool may result in increased heating losses of up to 70 %.

The risk of surface condensation is high in thermal bridges. The inside surfaces in the vicinity of the thermal bridge are greatly chilled, which may give rise to surface condensation. This risk is especially high in industrial buildings that house high moisture environments. If the transportation of moisture vapour cannot be prohibited from the inside by an efficient vapour barrier it is possible that condensation on the chilled surfaces inside the structure may cause serious problems.

The chilled parts on the inside surfaces of a structure may cause local soiling. This phenomenon is thought to be caused by thermal diffusion where dust particles are attracted to a colder surface and then fasten there.

The negative effects of thermal bridges may easily be avoided by the application of elementary building physics. The best method is to cut off the thermal bridge a with strip of material with a low coefficient of thermal conductivity such as mineral wool board.

The thermal conductivity break-off may be placed on the inside or the outside of the thermal bridge, the effect on thermal conductivity being just as good in both cases. One advantage to be gained by breaking the bridge on the outside surface is that the overall temperature of the stud inside the structure will rise, thereby reducing the risk for condensation.

Apart from a correct method of construction it is important that on-site construction methods are well thought-out and that workmanship is of high class. Unintentional thermal bridges are often the result of the thermal insulation is poorly fitted and not checked before boarding in.

The real effect of thermal bridges and the actual coefficient of thermal conductivity of a structure were previously determined by laboratory testing. It is now possible to calculate the effect of thermal bridges quite simply by using the method in Swedish Standard SS 02 42 30. The same method has been published by Swedisol /2/. The Swedish manufacturers of sheet metal products give, in their product catalogues, the effects of thermal bridges on the k-value of a structure.

Table 1 shows examples of the required thickness of thermal insulation for different stud and purlin types in order to achieve a certain k-value. In order that a timber stud wall should have a k-value of 0.25 $W/m^2\,^0C$ it must have a 150 mm thickness of mineral wool. If the timber stud is replaced by a homogenous Z-stud of steel, then the thickness of mineral wool must be doubled if the wall is to have the same mean k-value. By varying the type of thermal bridge compensation it is possible to greatly reduce the thickness of mineral wool and at the same time maintain the k-value.

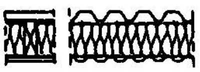
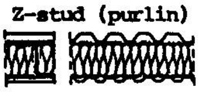
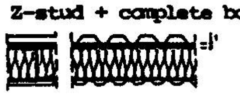
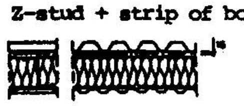
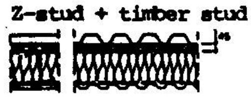
Design alternative	k-value	Kod	c 1 200		Kod	c 1 500	
Timber stud							
	0.25	-	155		-	153	
	0.30	-	127		-	126	
	0.45	-	81		-	81	
Z-stud (purlin)							
	0.25	2A1	344		2B1	296	
	0.30	2A2	270		2B2	234	
	0.45	2A3	152		2B3	133	
Perforated stud (purlin)							
	0.25	-	200		-	200	
	0.30	-	150		-	150	
	0.45	-	?		-	?	
Z-stud + complete board			t=15	t=30			
	0.25	4A1	261	207	4B1	230	185
	0.30	4A2	198	154	4B2	174	139
	0.45	4A3	103	74	4B3	94	68
Z-stud + strip of board			t=15				
	0.25	5A1	270		5B1	240	
	0.30	5A2	208		5B2	186	
	0.45	5A3	114		5B3	105	
Z-stud + timber stud + board							
	0.25	6A1	217		6B1	190	
	0.30	6A2	150		6B2	138	
	0.45	6A3	67		6B3	59	

Table 1. Calculated insulation thickness (mineral wool $\lambda = 0.040\ W/m\,^0C$) for design alternatives of thermal bridge reduction and for varied stud and purlin distances.

In a light-weight sheet metal wall structure it is often the case that a considerable quantity of spacers and extra studs are added on site for example when fitting windows or ducting. These extras often increase the heating losses of the building, and are seldom shown on drawings or considered when calculating energy losses or k-values. These details are often solved by the site foreman and it is easy to add extra studs and spacers without considering the consequences. All such details should be shown on working drawings and taken into consideration when calculating k-values. Homogenous surface to surface steel studs and purlins must be avoided at all costs. Spacers can be made from wood or wood and mineral wool board. There is considerable room far improvement and development in this field.

RECENT APPLICATIONS

Single storey industrial-type buildings in steel and with sheet steel cladding that are well insulated and have good air-tightness are now being built in Sweden. Several buildings have been tested for air-tightness by using new test method specially designed for large buildings. The buldings were even thermographed during testing in order to seek out possible loacations of air leakage. The techniques previously described have shown themselves to be fully applicable in real situations. It has also become evident that the extra costs involved in improving the air-tightness of the buildings are insignificant and in most cases not even extra costs when the tradesmen have become used to these new ideas. The results from the pressure tests show that it is fully possible to achieve a degree of air-tightness that gives a leakage of less than 4 m^3 per m^2 wall and roof area at an excess pressure level of 50 N/m^2. A number of methods for eliminating thermal bridges in steel studs and purlins have also been developed.

The techniques described have even been applied to the construction of low energy consuming indoor tennis facilities. By choosing well insulated and air-tight structures the energy losses in the buildings are so small as to virtually eliminate the need for heating and ventilation services.

TENNIS CENTRE, EKERÖ

Construction data:	34.5 x 35.5 m (two courts, tennis only) 4 x 8m two-storey entrance bulding minimum height at net 7 m, minimum height at base line 4.5 m Roof of steel trusses and purlins
Roof construction: (outside to inside)	Plagan trapezium profiled sheet cladding, 22 cm mineral wool k-value 0.20 W/m^2 ^0C
Wall construction: (outside to inside)	HE steel columns. Horizontal glulam studs. Plagan cladding, 17 cm mineral wool, timber panel up to 4 m, plagan sheet on gables. k-value 0.25 W/m^2 ^0C
Foundations:	24 column support of in-situ reinforced concrete onto existing edge beam
Floor surface:	Deco-Turf on existing asphalt surface
Lighting:	84 fluorescent fitting of 3 x 58 W
Heating:	4 Infra-red heaters above each base line (2 KW per court). Reserve heating 10 kW (construction dryer plant)
Ventilation:	Allowance made for fitting of extractor fan if necessary

ENERGY CONSUMPTION

The mean weekly temperature inside and outside the bulding has been continuosly recorded during the heating seasons 1983/84 and 84/85. The temperature inside the building has never been below a mean weekly value of +12 ^{0}C. During the period nov. 83 to March 84 the mean weekly temperature was +14 ^{0}C, se fig 8. During the winter of 1983/84, which was relatively mild, the building was never heated with the installed heating system. The heat produced by the lighting system was sufficient to keep the building at a suitable temperature in which to play tennis. It was first during the extreme winter of 1984/85 when the mean weekly temperature fell to -10 ^{0}C for 6-8 weeks (which is 6-8 ^{0}C below the mean monthly average for Stockholm) that the infra-red roof panels were used.

The total annual energy consumption, which is almost totally used for lighting is 70 000 kWh.

Well insulated and air-tight buildings may therefore be equipped with simplified services and have extremely low energy consumption.

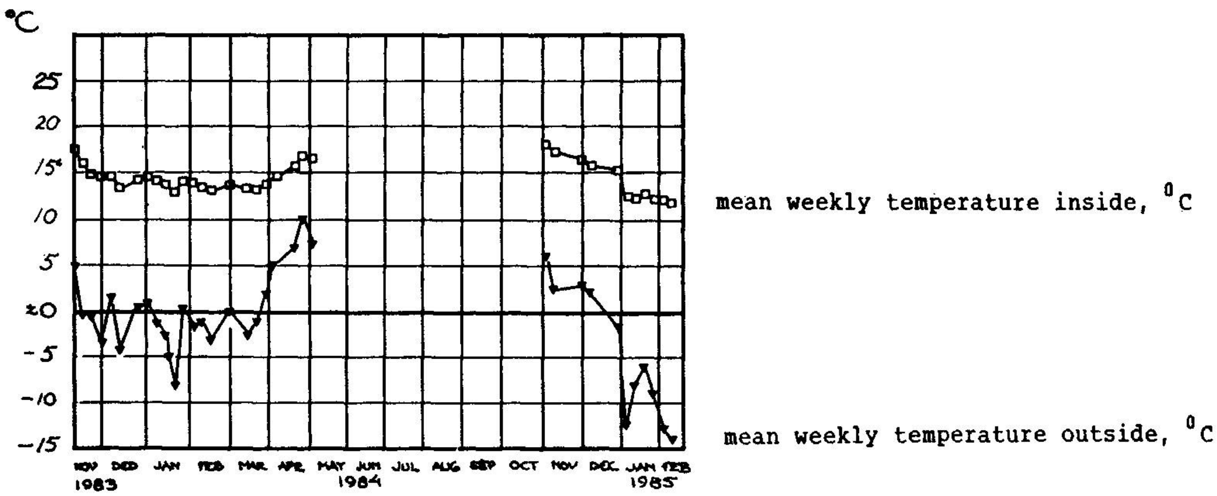


Fig 7 Mean weekly temperature outside and inside respectively recorded at the Ekerö Tennis Centre during Nov. 1983 to Feb. 1985

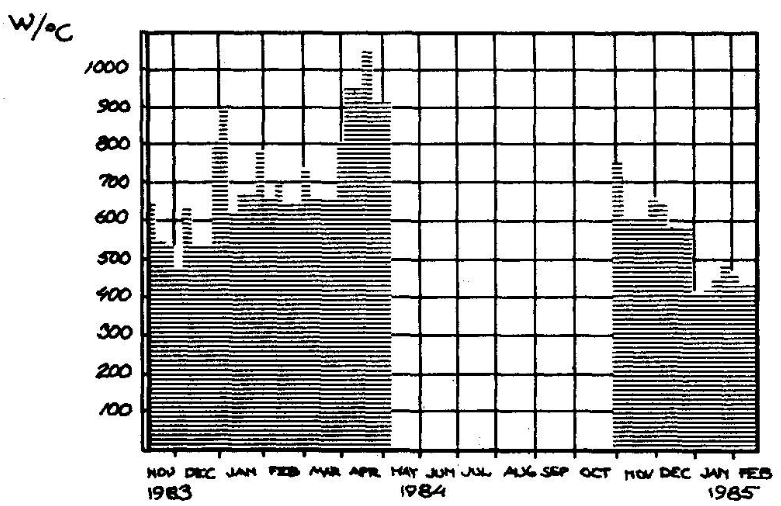


Fig 8 Energy consumption for the Ekerö Tennis Centre curing Nov. 1983-Feb. 1985. No recording during May 1984-Oct. 1984.

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