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SESSION C

Façades and Energy

Façades et énergie

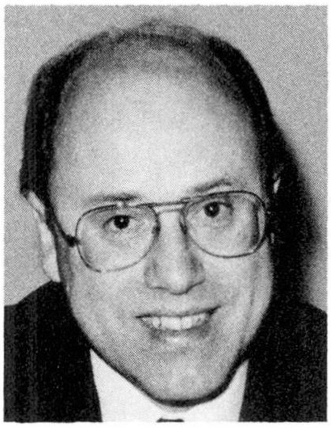
Fassaden und Energie

Energiebilanz von Fassaden im Sommer und Winter

Energy Balance of Façades in Summer and Winter

Bilan énergétique de façades en été et en hiver

Karl GERTIS
Prof. Dr.-Ing. habil.
Universität Stuttgart
Stuttgart, BR Deutschland



ZUSAMMENFASSUNG

Im Fassadenbau gewinnen die bauphysikalischen und energietechnischen Fragen immer mehr an Bedeutung. Der sommerliche und winterliche Wärmeschutz von Fassaden greifen stark in die Planung und die Ausführung der Fassaden ein. Die Betriebskosten des Gebäudes und die Komfortbedingungen für die Gebäudenutzer werden ebenfalls von der Energiebilanz der Fassaden beeinflusst.

SUMMARY

Questions of building physics and energy savings are gaining more and more importance in façade construction. Both summer and winter heat insulation are decisive factors in the planning and design of façades. The heating costs of a building and the comfort conditions for the occupant are also influenced by the energy balance of facades.

RÉSUMÉ

On se préocuppe de plus en plus des problèmes physiques et énergétiques dans le domaine de la construction de façades. Leur conception et réalisation tient compte des températures extrêmes en été et en hiver. En effet, le coût d'exploitation et le confort d'un bâtiment dépendent du bilan énergétique des façades.

1. Einleitung

Das energetische und bauphysikalische Verhalten von Fassaden gewinnt in letzter Zeit immer mehr an Bedeutung, weil man erkannt hat, daß von den bauphysikalischen Eigenschaften der Fassade das Wohlbefinden der Insassen, die in den Räumen hinter den Fassaden arbeiten bzw. wohnen müssen, und die energiespezifischen Betriebskosten des Gebäudes in starkem Maße abhängen. Die Energiebilanz der Fassaden spielt dabei im Sommer und Winter eine wesentliche Rolle. Im Sommer soll möglichst wenig Sonnenenergie in Räume dringen, damit sich dort komfortable Verhältnisse einstellen. Auch soll die Fassade baukonstruktiv so ausgebildet werden, daß sie der thermischen Beanspruchung standhält. Im Winter muß die Fassade einen wirtschaftlich optimalen Wärmeschutz aufweisen und - trotz des Wärmeschutzes - die im Winter erwünschte Solarenergie eintreten lassen. Diese z.T. kontroversen Funktionen zu erfüllen, ist baukonstruktiv nicht ganz leicht; es erfordert gründliche bauphysikalische Kenntnisse.

Im folgenden wird - angewandt auf den Metallfassadenbau - gezeigt, wie man diese bautechnischen Prinzipien verwirklichen kann. Im wesentlichen sind dabei Fassadenkonstruktionen zu berücksichtigen, die aus Blechpanelen, Trapezblechbekleidungen oder aus Stahlrahmen-Tragwerken mit Gefachverfüllung bestehen. Am Stoß der einzelnen Gefache bzw. Platten können im Winter unangenehme Wärmebrückenprobleme auftreten, deren Lösung einer besonderen Sorgfalt bedarf.

2. Sommerliche Beanspruchung der Fassaden

Je nach Orientierung und Tageszeit können auf Fassaden beträchtliche Strahlungsenergien im Sommer auftreffen. Bild 1 vermittelt

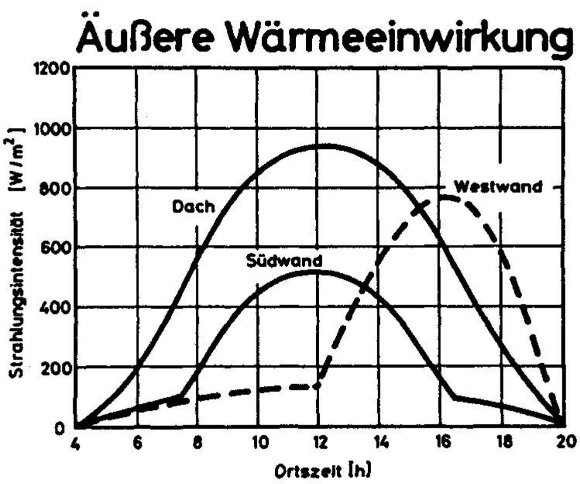


Bild 1 Zeitliche Verläufe der Strahlungsintensitäten einer Süd- und Westfassade, sowie eines Flachdaches, während eines strahlungsreichen Sommertages.

einen Überblick über den Zeitgang der Strahlungsbeanspruchung. Man erkennt, daß eine Südfassade im Sommer - wegen des steilen Sonnenstandes zur Mittagszeit - nur tangierend von der Sonne getroffen wird und entgegen einem verbreiteten Irrtum weniger Strahlung empfängt als eine Westfassade; diese erhält am Nachmittag höhere Intensitäten, weil die Sonne flach auf sie auftritt. In den Vormittagsstunden wird eine Westfassade nur von diffuser Strahlung getroffen; direkte Strahlung empfängt eine Westfassade erst ab 12 Uhr.

Je nach der Absorptionsfähigkeit, die in erster Linie von der Farbe bestimmt wird, fällt die Erwärmung der Fassade bei Besonnung stärker oder schwächer aus. Bild 2 zeigt an Hand einer Leichtbetonaußenwand, wie stark die Farbe der Außenoberfläche die Erwärmung beeinflußt. Während sich die schwarze Fassade auf

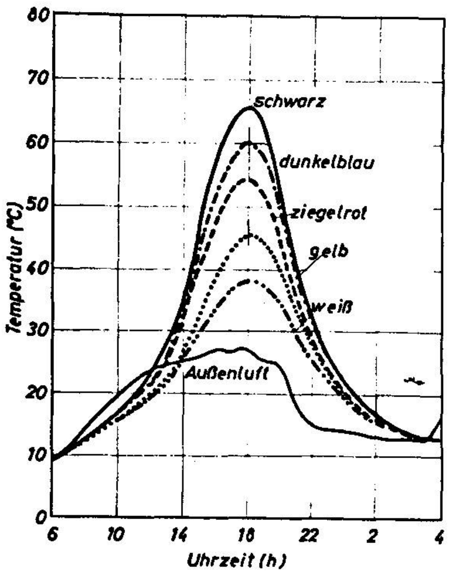


Bild 2 Zeitverläufe der Außenoberflächentemperatur einer Westwand (Leichtbeton) während eines strahlungsreichen Sommertages. Die Wände unterscheiden sich nur durch die Farbe. Der konstruktive Aufbau ist in allen Fällen identisch.

Zum Vergleich ist auch der Verlauf der gemessenen Außenlufttemperatur eingezeichnet.

knapp 70 °C erwärmt, bleibt die weiße Oberfläche mit ca. 40 °C relativ kühl. Dunkle Oberflächen werden thermisch stärker beansprucht als helle. In extremen Fällen können sommerliche Temperaturen bis zu 90 °C an Fassaden auftreten.

Bei derartig hoher thermischer Beanspruchung verformen sich die Fassaden aufgrund der thermischen Längenänderungen. Die Verformungen beruhen einmal auf Dehnungen bzw. Konstruktionen bei Erwärmung bzw. Abkühlung. Da der Fassadenquerschnitt aber nicht gleichmäßig erwärmt bzw. abgekühlt wird, ergeben sich zusätzlich auch Wölbungen, welche die in Bild 3 veranschaulichte Größenordnungen annehmen können. Man ersieht aus Bild 3, daß sich

Thermische Beanspruchung

Metall-Bauelement (5 m lang)	Wölbung (mm)	
	hell	dunkel
Sandwich mit Stahl-Trapezblech  (100 mm dick)	4,7	10,9
Sandwich mit Alu-Deckschicht  (100 mm dick)	11,3	26,2

Bild 3 Thermisch bedingte Wölbungen von Metall-Fassadenteilen (5 m Gefachbreite) mit heller bzw. dunkler Farbe der Außenoberfläche.

Sandwich-Konstruktionen stärker wölben als z.B. Trapezblechteile, wenn die Deckschichten der Sandwich-Bauteile durchgehend sind. Oftmals besitzen die Metallteile (Stahl-, Alubleche) andere Längenänderungskoeffizienten wie die Dämmschichten im Kern der Elemente.

3. Sommerlicher Wärmeschutz

Metallfassaden stellen meistens Leichtfassaden dar, mit denen - sehr zu Unrecht! - häufig ein Barackenklima im Sommer assoziiert wird. Der sommerliche Wärmeschutz einer Fassade hängt, wie Bild 4 zeigt, von fünf Einflußgrößen ab, unter denen die instationären Eigenschaften der Fassade selbst, d.h. deren Wärmespeicher- und Wärmedämmfähigkeit, auf Rang fünf stehen. Dies bedeutet, daß ein "Barackenklima", wenn es wirklich zustande kommt, wesentlich von vier anderen Parametern verursacht wird, nämlich:

- von mangelhaftem Sonnenschutz der Fenster (Rang 1)
- von der mangelhaften Belüftung des Raumes (Rang 2)

- von falsch geplanter Orientierung der Glasflächen (Rang 3)
- von mangelhafter Speicherfähigkeit des Gebäude-Innern.

Bild 4 Bedeutung der einzelnen Einflußgrößen für den sommerlichen Wärmeschutz einer Fassade. Die Nummerierung stellt keine Aufzählung, sondern eine Rangfolge für die einzelnen Parameter dar.

Unbehagliche sommerliche Temperaturzustände in Räumen hinter Metallfassaden sind somit nicht primär auf die Leichtfassaden zurückzuführen.

4. Winterliche Energiebilanz

Daß der Wärmeschutz unserer Fassaden wegen der gestiegenen Energiepreise verbessert werden muß, ist heutzutage bereits selbstverständlich geworden. Dabei ist nicht jene Ausführung als die "wirtschaftlichste" anzusehen, welche die geringsten Investitionskosten aufweist; vielmehr müssen die späteren Betriebskosten und die Investitionskosten zu Gesamtkosten zusammengefaßt werden. Dies ergibt die in Bild 5 veranschaulichten Größenordnungen für den k-Wert von Außenbauteilen. Man ersieht, daß bei Fassaden ein k-Wert zwischen 0,3 und 0,6 W/m^2k angebracht ist.

Ein guter Wärmeschutz, wie in Bild 5 angegeben, nützt wenig, wenn nur der Gefachbereich der Fassaden gut gedämmt ist und an den An-

Wirtschaftlich optimaler Wärmeschutz

Außenwände	:	k = 0,3 - 0,6 W/m²K
Kellerdecken	:	k = 0,3 - 0,5 W/m²K
Dächer	:	k = 0,15 - 0,4 W/m²K
Fenster	:	Doppelverglasung (evt. mit temporärem Wärmeschutz)

Bild 5 Größenordnungen des wirtschaftlich optimalen Wärmeschutzes von Außenbauteilen anhand des k-Wertes.

schluß- und Stoßstellen der Elemente Wärmebrücken auftreten (vgl. Bild 6). Der Wärmeschutz eines Fassadenelementes kann reduziert oder zunichte gemacht werden, wenn am Plattenstoß oder am Anschluß-

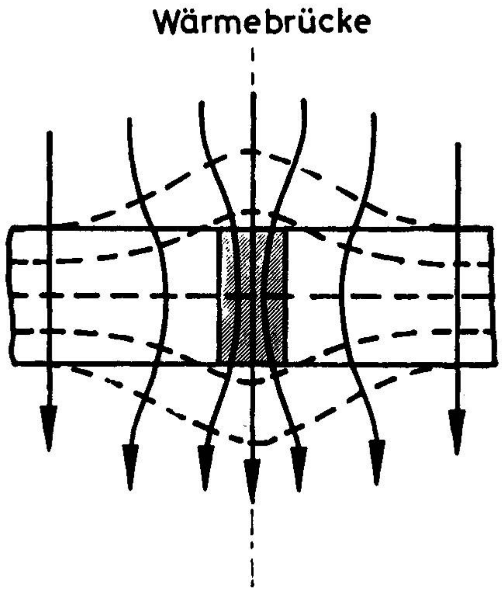


Bild 6 Schematische Darstellung einer Wärmebrücke.
Gestrichelte Kurven: Isothermen
Ausgezogene Kurven: Adiabaten

punkt, an dem die Gefache an das Tragskelett grenzen, eine Wärmebrücke entsteht. Wie stark der Wärmeschutz hierdurch beeinträchtigt wird, zeigt Bild 7, in dem für eine hinterlüftete

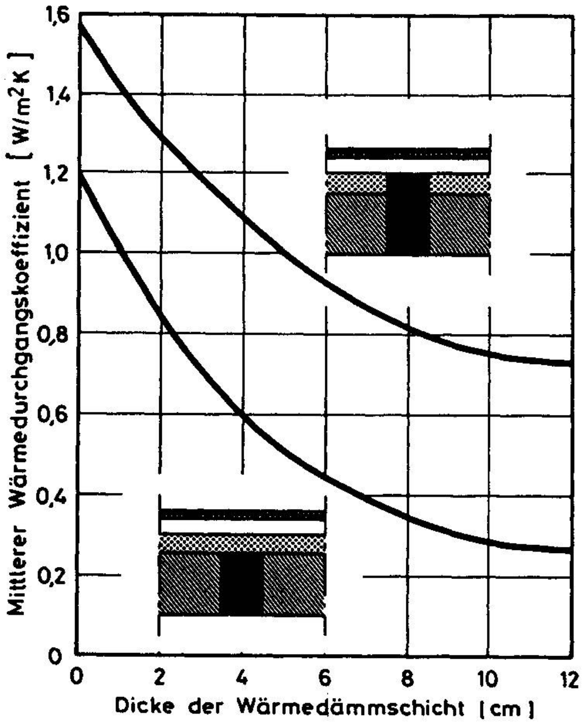


Bild 7 Mittlerer Wärmedurchgangskoeffizient mit am Anschluß unterbrochener und durchgezogener Wärmedämmschicht, in Abhängigkeit von der Dämmschichtdicke.

Fassade der Wärmedurchgangskoeffizient wiedergegeben ist, wenn die Wärmedämmschicht am Anschluß unterbrochen (obere Kurve) bzw. durchgezogen wird (untere Kurve). Man erkennt, daß z.B. bei einer 10 cm dicken Dämmschicht die Unterbrechung eine Verschlechterung des k-Wertes von 0,3 W/m^{2}k auf ca. 0,7 W/m^{2}k erbringt. Wärmebrücken müssen in Fassaden also sorgfältig bedacht werden. Man kann sie durch planerische und konstruktive Maßnahmen erheblich reduzieren. Man muß ferner bei der Ausführung der Fassaden in der Praxis auch sorgsam darüber wachen, daß am Plattenstoß oder an den Anschlußstellen nicht "geschlampt" wird.

5. Praktische Konsequenzen

Aus der Betrachtung des bauphysikalischen Verhaltens und der Energiebilanz von Fassaden im Sommer und Winter können folgende praktische Schlußfolgerungen abgeleitet werden:

- Barackenklima in Räumen hinter Leichtfassaden entsteht nicht wegen der Fassadenbauart, sondern primär wegen mangelhaften Sonnenschutzes am Fenster.

- Fassaden können eine hohe thermische Beanspruchung im Sommer erfahren, besonders Westfassaden mit dunklen Außenoberflächen. Dies führt zu Längenänderungen und Wölbungen.
- Der winterliche Wärmeschutz von Fassaden muß aus Energieeinspargründen k-Werte im Bereich von 0,3 bis 0,6 W/m^2k aufweisen.
- Wärmebrücken an den Anschluß- bzw. Stoßstellen von Fassadenelementen müssen baukonstruktiv, planerisch und ausführungsmäßig mit großer Sorgfalt behandelt werden.

L'acier en façade: une réponse aux questions énergétiques

Die Stahlfassade: eine Antwort auf energietechnische Probleme

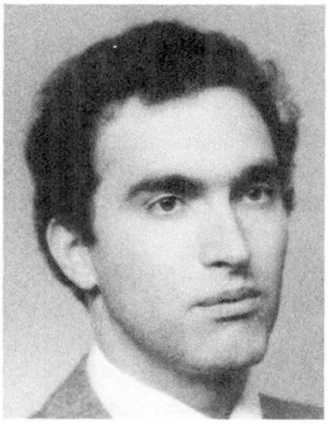
Steel Facades and Energy Considerations

Michel LE CHAPELLIER
G.R.E.P.S.
Université de Technologie
Compiègne, France

Pierre BOULLIER
G.R.E.P.S.
Université de Technologie
Compiègne, France

Faleh AL HAMDANI
Université de
Technologie
Compiègne, France

Michel Le Chapellier, né en 1948, est Docteur Contrôle des Systèmes depuis 1978. Il s'occupe de problèmes d'économies d'énergie dans le bâtiment et l'industrie.



Pierre Boullier, né en 1956, est Docteur-Ingénieur Automaticien, il se consacre à l'étude de la conduite des systèmes énergétiques.

Faleh Al Hamdani, né en 1953, Ingénieur, prépare une thèse de Docteur-Ingénieur sur les méthodes de climatisation à partir de la convection naturelle.

RÉSUMÉ

Les tôles acier nervurées, prélaquées et les panneaux sandwich permettent de réaliser plusieurs types de gains énergétiques qui sont étudiés au GREPS à l'Université de Compiègne: la gestion du chauffage intermittent, la conception de l'éclairage, les gains solaires directs, les systèmes solaires actifs et la protection contre le rayonnement en zone tropicale.

ZUSAMMENFASSUNG

Die vorbeschichteten Rippenstahlbleche und die Sandwich-Tafeln ermöglichen eine Reihe von Energieeinsparungen, welche von GREPS (Universität Compiègne) untersucht werden: intermittierende Steuerung der Heizung, Konzeption der Beleuchtungsanlage, Energiegewinne durch direkte Sonneneinstrahlung, aktive Solar-Systeme, Einstrahlungsschutz in tropischen Zonen.

SUMMARY

Coated ribbed steel plates and sandwich panels offer a number of advantages from the viewpoint of energy saving, which have been investigated at GREPS (University of Compiègne), i.e. intermittent control of heating, concept for lighting, energy savings by utilizing direct solar radiation, active solar systems, and solar radiation insulation in tropical zones.

INTRODUCTION

Depuis 1979 le G.R.E.P.S. a étudié différentes techniques visant à valoriser l'usage de produit acier plat en toiture et façade de bâtiment.

Nous présentons ici plusieurs études et réalisations :
- l'étude sur les économies d'énergie dans les locaux sportifs,
- l'utilisation de tôles fortement nervurées comme pare-soleil intérieur,
- le bardage triple peau (bardage thermique) en construction industrielle pour la production d'air préchauffé,
- la recherche sur les applications du bardage thermique pour la climatisation naturelle en zone tropicale humide.

1.- FACADES ACIER ET INTERMITTENCE

Dans les bâtiments à occupation intermittente, l'inertie a une influence très grande sur les consommations. La figure 1 permet de comparer l'évolution de température de deux bâtiments, de déperditions identiques mais d'inertie très différente, ainsi que la chronologie des consommations correspondantes. On peut en tirer deux conclusions : dans un bâtiment peu inerte, occupé de façon intermittente :
- la consommation est plus faible
- la puissance installée pour le chauffage est plus faible.

Lors d'une étude réalisée sur des gymnases, deux solutions techniques au niveau du bâti ont été envisagées : d'une part, une construction légère : plancher bois, façade et toiture en panneaux sandwich acier et d'autre part une construction lourde : sol sportif sur terre-plein, façades (jusqu'à 3 m) et pignons en agglomérés de béton. L'inertie du premier ressort en moyenne à 15 kg/m^2 d'enveloppe, celle du second à 45 kg/m^2. Quel que soit le mode de gestion, la différence est significative.

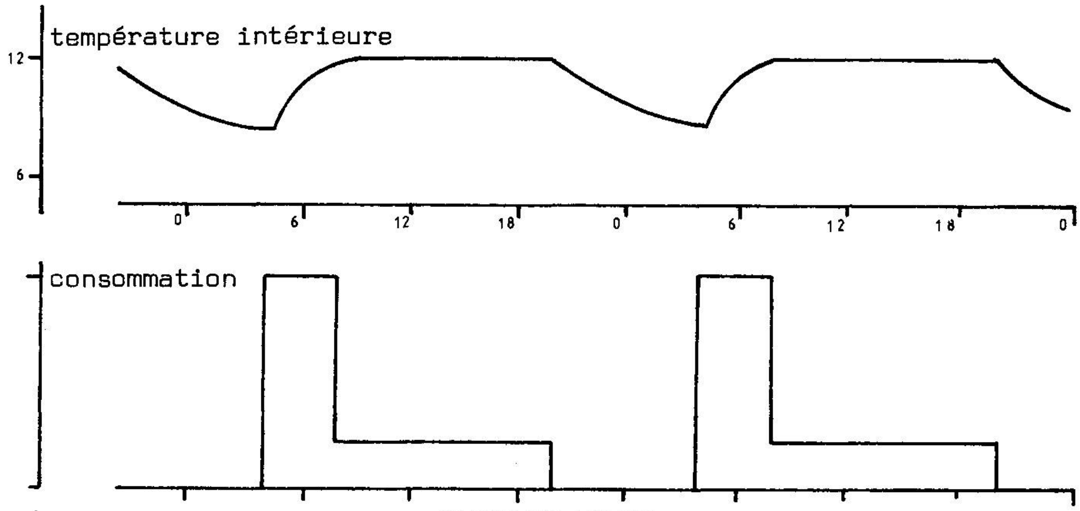
- Avec un chauffage traditionnel (aérothermes) les besoins du gymnase lourd sont de 51222 kWh/an, ceux du gymnase léger de 39027 kWh/an soit 24% de moins (gymnase à TRAPPES, 198 m^2 de vitrages en façade Sud). Un gymnase d'inertie intermédiaire (sol sportif sur terre-plein, enveloppe sandwich) a des besoins de 44232 kWh/an.

Dans d'autres cas d'orientation, l'écart peut être encore plus important : réduction de moitié par allègement de l'enveloppe.

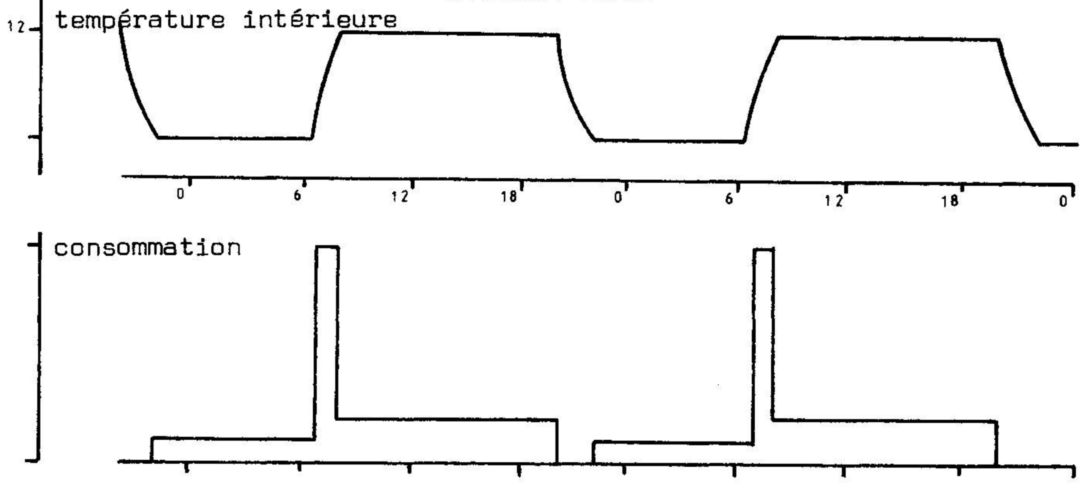
- En l'absence de chauffage traditionnel, remplacé par une combinaison de surfaces transparentes (gain direct) et d'un système à air (gain différé) l'écart se traduit par une différence de confort : entre 12 h et 13 h, il y a 69 jours où le gymnase lourd n'atteint pas les 12° requis, contre 44 jours pour le gymnase léger (- 36% !). Si on place plus bas la limite d'inconfort, par exemple à 9°C, la différence dépasse 50%.

Les résultats obtenus se généralisent aisément à tous les locaux chauffés à occupation intermittente : activités industrielles, artisanales ou équipements collectifs pour lesquels une réponse rapide en température et une consommation énergétique faible sont des facteurs essentiels d'utilisation rentable et confortable.

Soulignons cependant que la baisse de l'inertie induit une plus grande sensibilité aux surchauffes. Celles qui sont d'origine interne (machines, occupants, éclairage) peuvent être maîtrisées par une bonne conception du système, celles qui sont d'origine externe essentiellement les apports solaires directs - peuvent être également traitées par une bonne conception de l'enveloppe, profitant de la souplesse des produits acier.



BATIMENT LOURD



BATIMENT LEGER

2.- PARE-SOLEIL

Traditionnellement dans les grands halls (gymnase, hall de bâtiment de service, bâtiments industriels) les façades vitrées sont placées en façade Nord. Cependant, l'orientation en paroi verticale Sud ou en toiture permettrait de diminuer la consommation dûe au chauffage.

Dans une étude concernant la consommation d'énergie dans les gymnases réalisée pour le Ministère de la Jeunesse et des Sports, nous avons évalué la diminution de besoin de chauffage obtenue en déplaçant en façade Sud 198 m^2 de transparents doubles précédemment orientés au Nord.

LIEU	VITRAGES NORD	VITRAGES SUD	TYPE
TRAPPES	53154	44232	DOUBLE
STRASBOURG	70007	59225	DOUBLE
CARPENTRAS	79597	66969	SIMPLE

Cependant la disposition de grandes surfaces transparentes en façade Sud a deux inconvénients :

- la surchauffe du bâtiment,
- l'éblouissement des usagers.

Le système de pare-soleil qui a été expérimenté sur le gymnase de CONDE SUR NOIREAU (France) a pour but de supprimer ces inconvénients.

Les choix technologiques qui ont été fait, avaient pour but de réduire le coût. C'est pourquoi nous avons choisi des tôles d'acier fortement nervurées (MURECO) afin d'avoir une très grande portée entre appuis. Les tôles sont disposées à l'arrière des transparents situés en toiture et en façade Sud de manière à supprimer le passage du rayonnement direct qui est soit réfléchi, soit absorbé.

La chaleur provenant de l'absorption du rayonnement solaire est transférée à l'air. Cet air chaud peut être collecté en partie supérieure et utilisé comme pour tous les systèmes solaires à air (soit chauffage immédiat, soit stockage, soit éjecté à l'extérieur en période chaude).

3.- BARDAGE THERMIQUE POUR L'INDUSTRIE

Nous allons maintenant décrire une installation qui utilise un bardage triple peau :
- 2 peaux de panneaux sandwich
- 1 peau de bardage thermique.

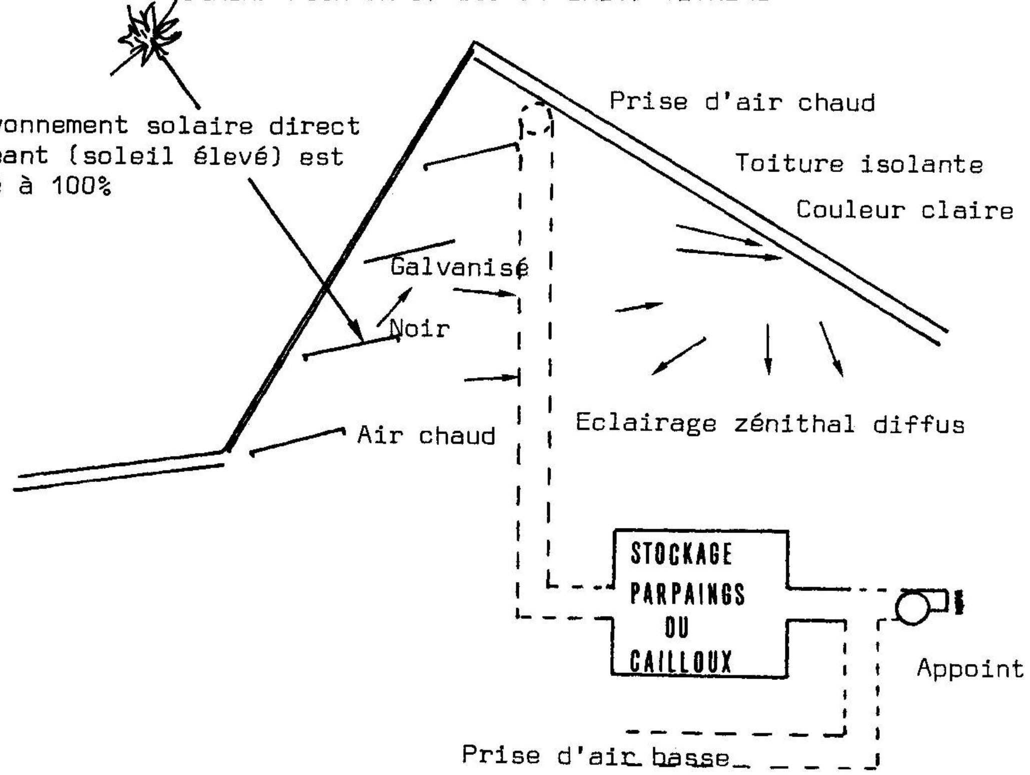
Dans ce cas la troisième peau est une tôle acier laquée qui va permettre de récupérer l'énergie solaire afin de chauffer l'air de renouvellement d'un atelier de peinture des Constructions Mécaniques de Bellande (France).

L'usine des Constructions Mécaniques de Bellande (Aubenas) a réalisé la construction d'un atelier de peinture comportant :
- 3 cabines : renouvellement d'air 32000 m /h, température 22°C
- 1 hall : température 20°C
- 1 étuve : renouvellement d'air 6000 m /h, température 52°C

Le projet de base ne comportait pas d'isolation spécifique et le chauffage de l'air et des locaux était assuré par un ou plusieurs brûleurs fuel.

La présente étude concernait l'étuve, le hall et une cabine de peinture et nous avons évalué l'intérêt de l'isolation ainsi que celui du bardage thermique en toiture servant à préchauffer l'air avant son passage sur les brûleurs fuel.

PARE-SOLEIL CAPTEUR SOLAIRE POUR SHEDS SUD ET BAIES VITREES



3.1.- Faisabilité technique de la toiture

En utilisant les produits de série, ONDATHERM pour les panneaux sandwich, et NERVESCO pour la tôle, les canneaux de circulation de l'air ont des sections de 0,08 m² par panneau. Sur une largeur de 30 m la section totale sera de 2,4 m².

Compte tenu de la morphologie de la section d'écoulement d'air, le coefficient d'ailette vaut 0,97.

(tôle de 0,75 mm, distance des canalisations 35 mm, coefficient de déperdition 10 W/m °C).

On en déduit la valeur du facteur solaire du capteur :

$$F_R = GCp/UL\ (1 - e^{-UCF'/GCp})$$

$$FR = GCp/U\ (1 - e^{-UF'/GCp})$$

avec G débit en kg/s m²
Cp chaleur massique de l'air J/kg°C
U coefficient de perte vers l'avant W/m²°C
F' facteur d'aillette

FR = 0,82

3.2.- Evaluation du gain annuel

Le gain annuel est déterminé par simulation heure par heure.
Nous utilisons pour la simulation le modèle de l'Université de Technologie de COMPIEGNE pour l'évaluation thermique des bâtiments industriels en considérant deux zones :
zone 1 : hall de peinture (22°C)
zone 2 : étuve (54°C)

Les données utilisées sont celles de CARPENTRAS (horaire et trihoraires).

	BASE	BASE + SOLAIRE	ISOLEE	ISOLEE + SOLAIRE
BESOINS 10 kWh	559	441	314	201
CONSOMMATIONS FUEL Tep	66,5	52,5	37	23,9

Base : 1 Tep couvre 8400 kWh besoins
Rendement 0,724

3.3.- Surcoût et économie

	Surcoût	Economie
Isolation	91 420	29,5 Tep/an
Solaire	62 680	13,1 Tep/an

4.- VENTILATION D'UN BATIMENT D'HABITATION A L'AIDE D'UN BARDAGE ABSORBANT L'ENERGIE SOLAIRE

Les exigences qui doivent être satisfaites pour la conception et la réalisation d'un bâtiment d'habitation sous les climats chauds et humides sont les suivantes :
- possibilité d'une ventilation permanente et efficace,
- protection contre le soleil et la pluie,
- élimination de températures élevées à l'intérieur au cours de la journée.

L'utilisation d'un bardage thermique pour les habitations de ces pays permet d'obtenir simultanément une bonne isolation thermique et une ventilation naturelle.

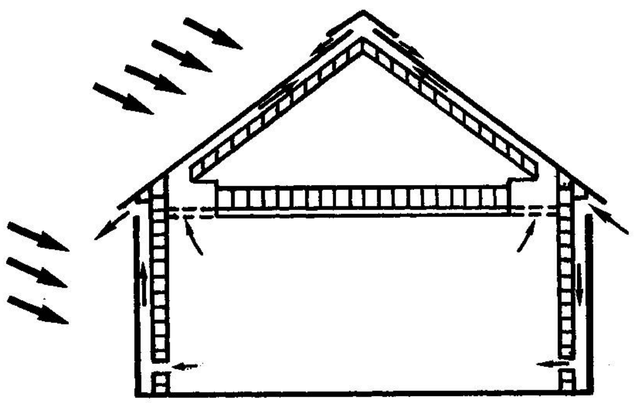
Un bardage thermique est constitué de deux parois séparées par une couche d'air ventilée essentiellement par convection naturelle. La première paroi est une tôle absorbante de l'énergie solaire et la deuxième paroi est formée par deux plaques métalliques planes emprisonnant une mousse de polyuréthane dont l'objectif est de réduire l'énergie thermique transmise à l'intérieur de l'habitation.

L'étude expérimentale du bardage a porté sur le rôle de certains paramètres opératoires et géométriques sur le débit de ventilation et sur l'énergie thermique évacuée. Les principaux paramètres étudiés sont :
- la puissance absorbée,
- la hauteur du bardage disposé verticalement,
- l'espacement entre les deux plaques constituant le bardage,
- la mise en place de chicanes sur la plaque absorbante du côté interne,
- la nature absorbante des plaques internes constituant le bardage.

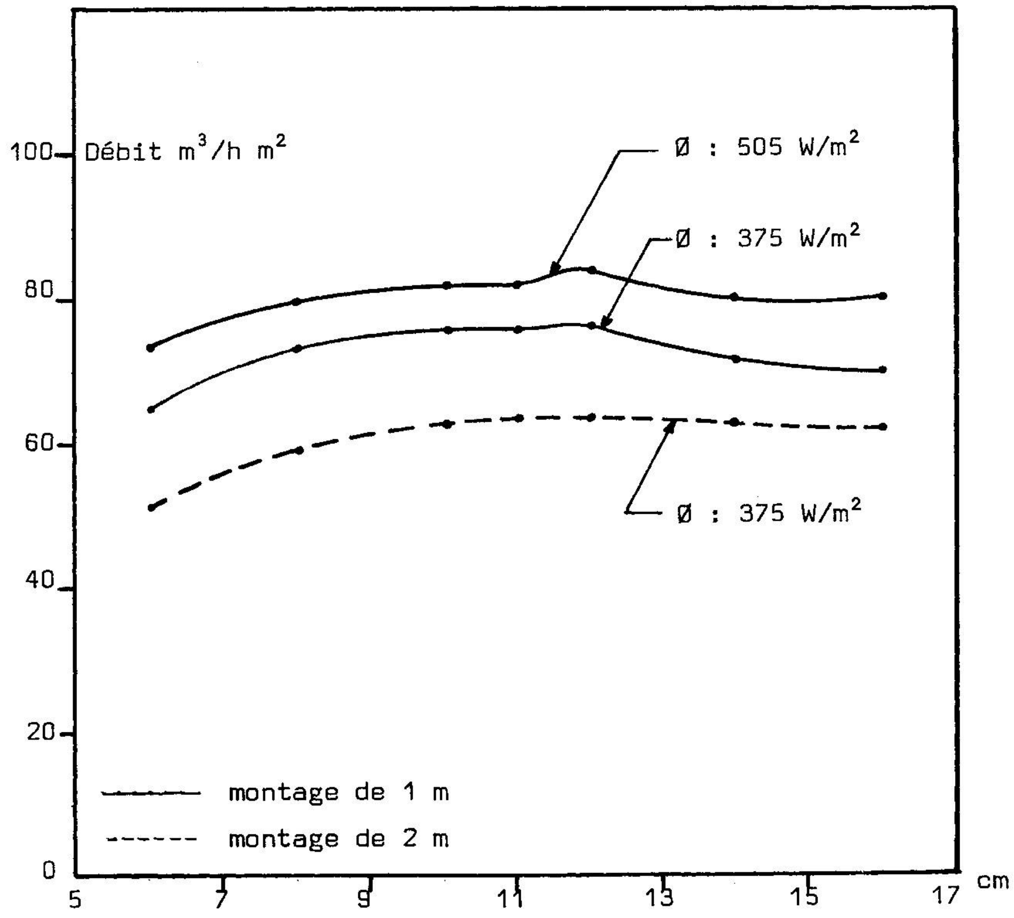
D'une manière générale, le débit d'air ventilé augmente avec la puissance absorbée. Pour une même puissance absorbée et une même unité de surface, le débit diminue avec la hauteur du bardage. La mise en place de chicanes sur la paroi absorbante provoque un accroissement du débit d'air ventilé. De même, en modifiant les propriétés rayonnantes des surfaces internes du bardage, l'augmentation des échanges de chaleur par rayonnement entraîne celle du débit d'air ventilé. Enfin, les autres paramètres étant fixés, il existe un espacement entre les deux plaques du bardage maximisant le débit d'air, l'épaisseur optimale variant légèrement avec les paramètres étudiés précédemment.

Avec l'ensemble des résultats précédents, nous pouvons, à présent, dimensionner une habitation située dans une région tropicale dont les conditions climatiques sont connues, tout en minimisant le coût de revient de la construction. Ce dimensionnement s'applique aux géométries étudiées qui représentent, cependant, des formes simples pouvant être rapidement réalisées à l'échelle industrielle.

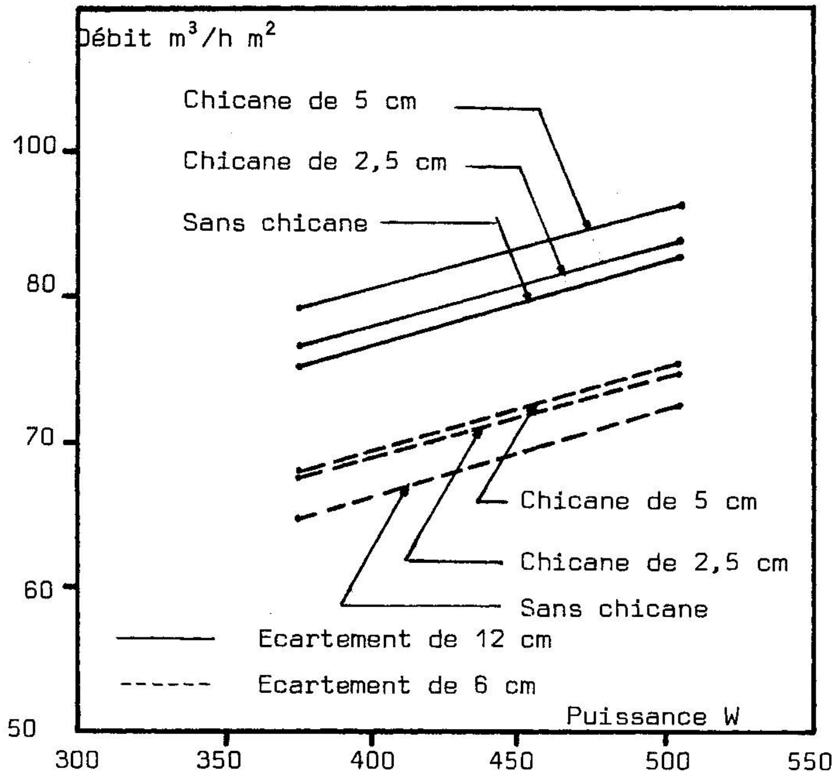
COUPE DE PRINCIPE



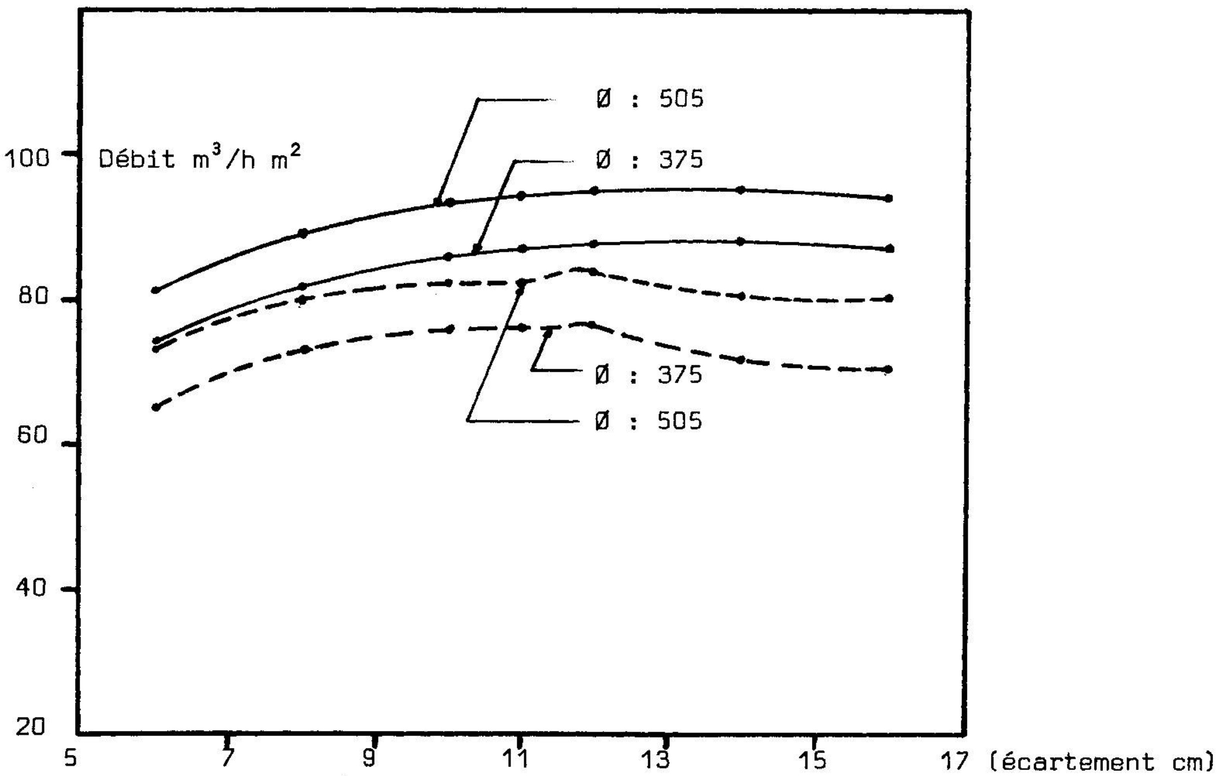
EVOLUTION DU DEBIT EN FONCTION DE L'ECARTEMENT POUR DIFFERENTES HAUTEURS



EVOLUTION DU DEBIT EN FONCTION DE LA PUISSANCE POUR DIFFERENTES CHICANES



EVOLUTION DU DEBIT EN FONCTION DE L'ECARTEMENT POUR DIFFERENTES TEINTES



Steel Buildings with Low Annual Energy Consumption

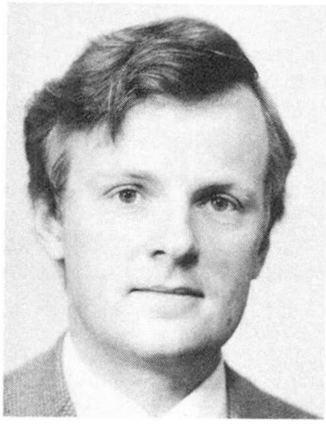
Bâtiments en acier à basse consommation annuelle d'énergie

Bauten in Stahl mit niedrigem Jahresenergieverbrauch

Arne ELMROTH
Professor
The Royal Institute of Technology
Stockholm, Sweden

Arne Elmroth, born 1937, received his MSc in Civil Engineering at the Royal Institute of Technology, Stockholm in 1961. He has conducted research in the field of Building Technology, in problems concerning moisture, air-tightness and energy conservation. He received his PhD in 1975 and became Professor of Building Technology in 1984.

Carl Michael JOHANNESSON
Architect
The Royal Institute of Technology
Stockholm, Sweden



Carl Michael Johannesson, born 1949, qualified as an architect at the Royal Institute of Technology, Stockholm in 1974. After practising as an architect he returned to the Royal Institute where he has studied building physics and financial problems associated with energy conservation. He received his PhD in 1982.

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.

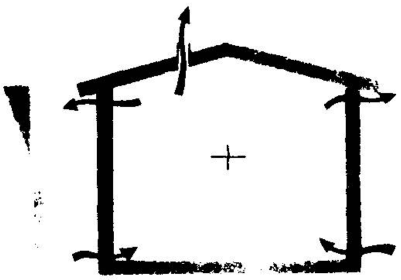
LIMIT AIR LEAKAGE

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.

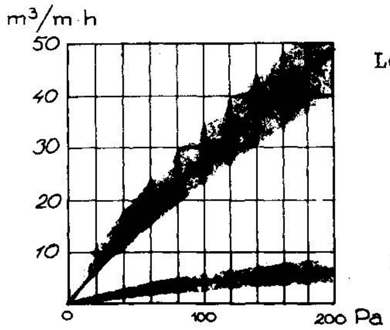
The governing force for air-leakage and ventilation in buildings is the difference in pressure of the air inside and outside the building. The forces affecting the air adjacent to and inside the building (excluding ventilation fans) and setting it in motion are wind and temperature. On a calm winters 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

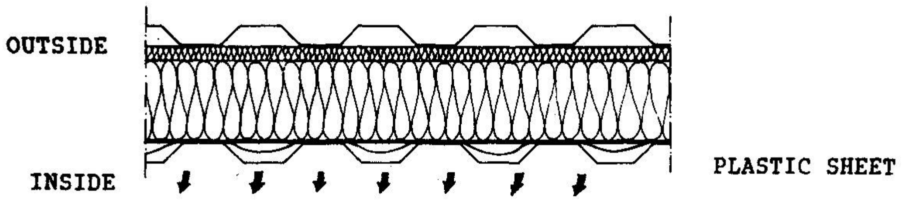
Fig 1 An insufficiently air-tight building where cold air seeps in at floor level and warm air leaks out at roof level due to thermal forces, wintertime. The prèssure gradient is for temperature related pressures on a calm day and fore evenly distributed air leakage.

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.

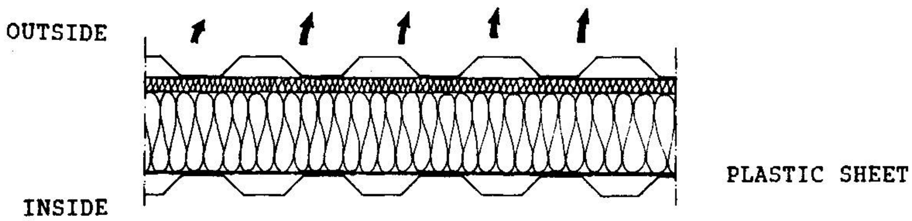


Lower pressure inside than outside

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.

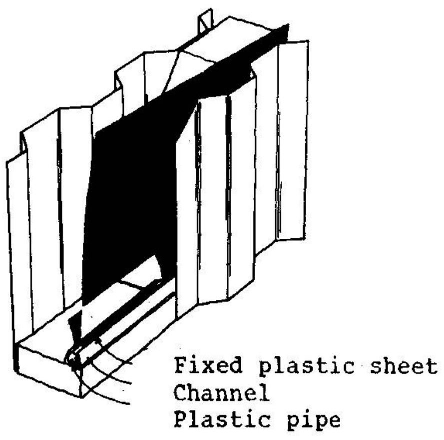


Fig 3 If the plastic sheet is fixed in a channel with a plastic pipe, electric conduit for example, excellent air tightness is achieved.

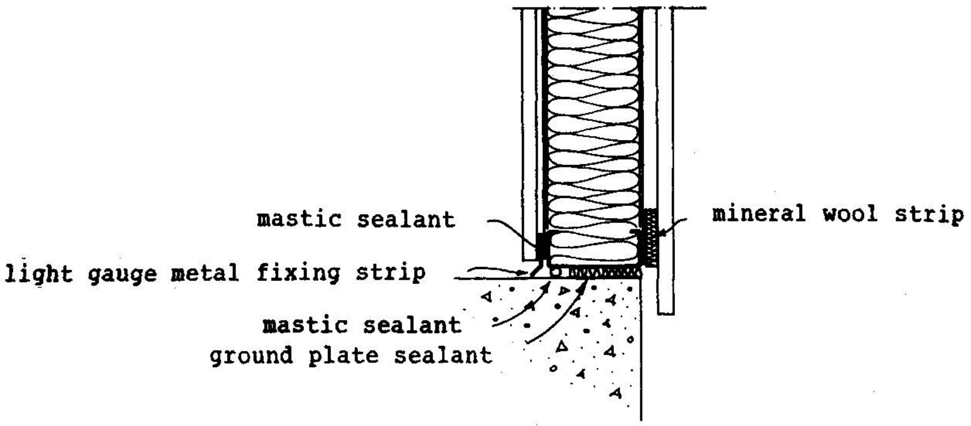


Fig 4 An alternative method of achieving good air-tightness in the ground plate detail is to fasten the plastic sheet with a special light gauge metal fixing strip. A mastic sealant or sealing strip placed between the plate and the sheet will ensure air-tightness. The joint between the ground-plate and 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.

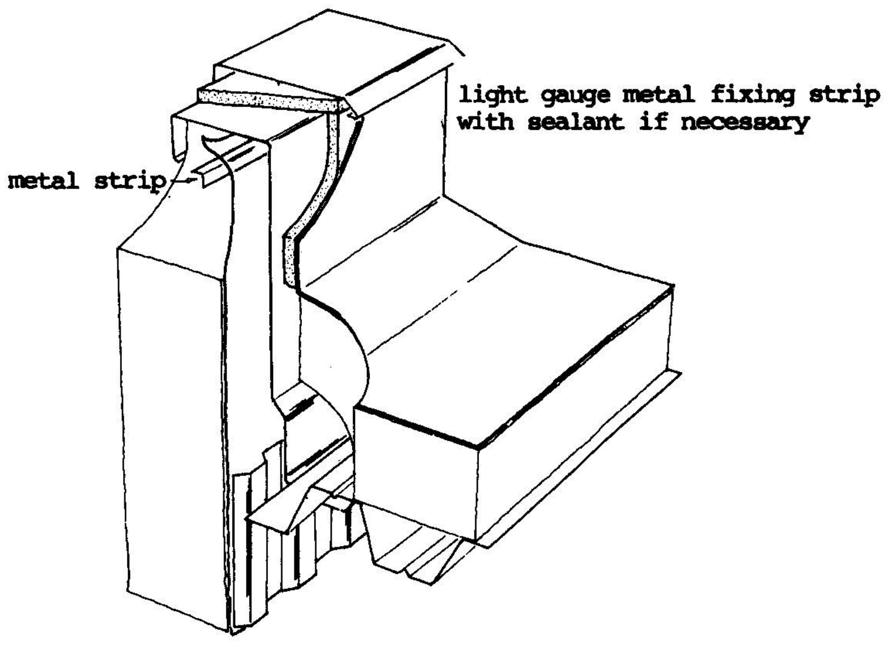
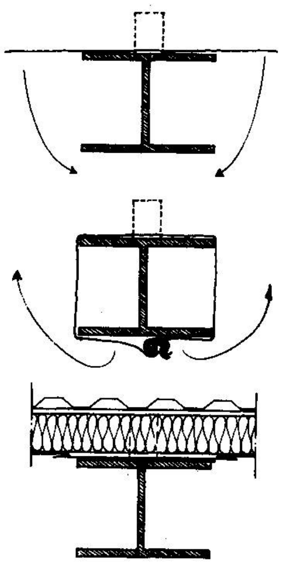


Fig 5 If the plastic sheet at the roof eaves is placed round the outside of the eaves beam there is a risk for air leakage being as the air pressure is often higher inside the building than outside. The sheet is drawn away from the beam and leakage occurs. The sheet must therefore be fixed with, for 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

Fig. 6 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.

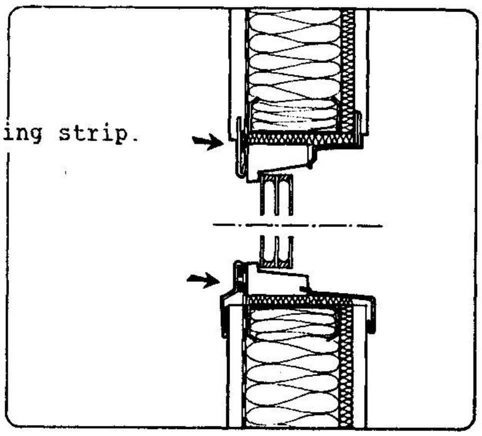


Fig 7 Window detailing. The plastic sheet in the wall is drawn over the window frame and fastened with a special sealing strip. An EPDM synthetic rubber sealing strip between the plastic sheet and the window frame considerably reduces the risk for air-leakage.

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.

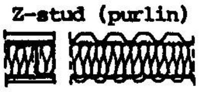
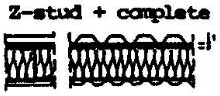
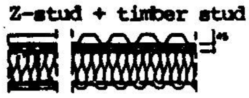
Design alternative	k-value	Kod	c 1 200		Kod	c 1 500	
Timber stud							
	0.25	-	155		-	153	
	0.30	-	127		-	126	
	0.45	-	81		-	81	
Z-stud (purlin)							
	0.25	2A1	344		2B1	296	
	0.30	2A2	270		2B2	234	
	0.45	2A3	152		2B3	133	
Perforated stud (purlin)							
	0.25	-	200		-	200	
	0.30	-	150		-	150	
	0.45	-	?		-	?	
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.

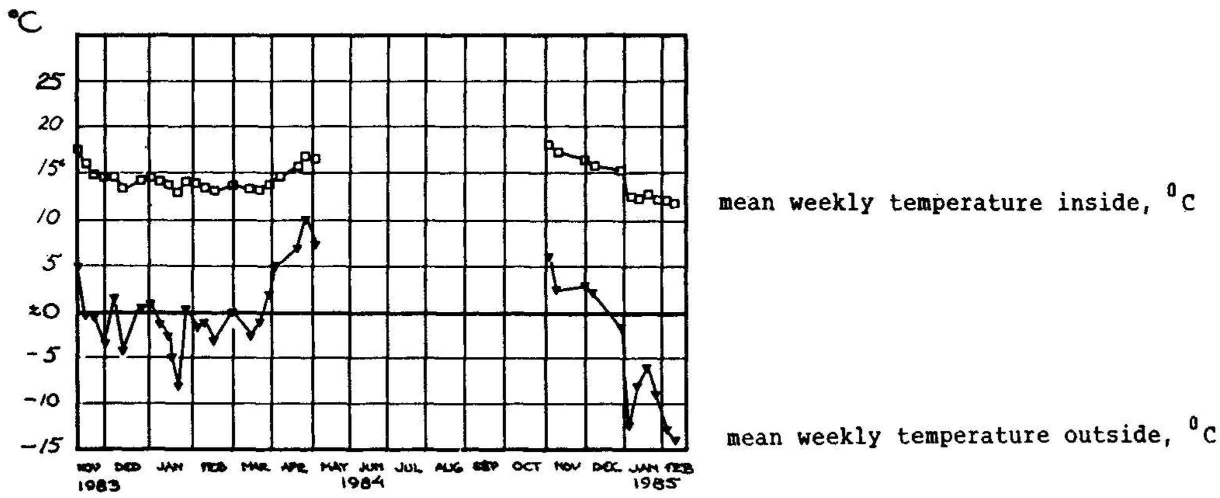


Fig 7 Mean weekly temperature outside and inside respectively recorded at the Ekerö Tennis Centre during Nov. 1983 to Feb. 1985

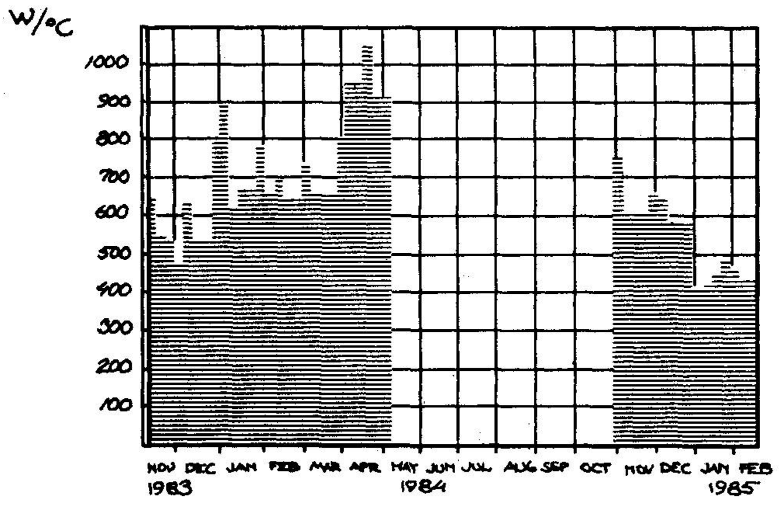


Fig 8 Energy consumption for the Ekerö Tennis Centre curing Nov. 1983-Feb. 1985. No recording during May 1984-Oct. 1984.

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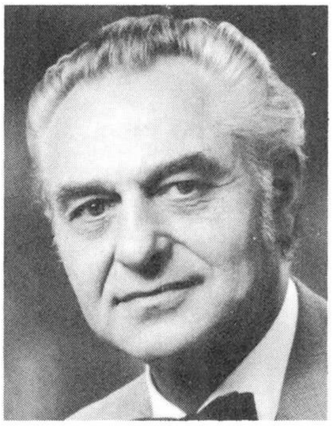
Fassadenelemente aus Metallblechpaneelen mit integrierten Kollektor- und Konvektorsystemen

Sheet Metal Facade Panels with Integrated Collector and Convector Systems

Panneaux métalliques de façades avec collecteurs et convecteurs intégrés

Friedrich HAFERLAND
Prof. Dr.-Ing. Architekt
Technische Hochschule
Delft, the Netherlands



Geboren 1924. Architekturstudium an der TH Hannover, BRD. Dort von 1967–73 Prof. für Baustoffkunde und Bauphysik. Seit 1973 Prof. für Ausbaukonstruktionen an der TH Delft, NL, Abteilung Civiele Techniek.

ZUSAMMENFASSUNG

Dieser Beitrag behandelt Vorschläge zur konstruktiven Lösung von Vorhangfassaden mit beidseitig wasserdurchströmten Metallblechpaneelen, die an der Aussenseite eine Kollektorfunktion zur Aufnahme absorbierter Sonnenenergie und an der Innenseite eine Konvektorfunktion zur Abgabe dieser Energie an den Raum erfüllen können. Damit kann sowohl im Winter ergänzend geheizt, als auch im Sommer gekühlt werden. Den Fassaden-Mehrkosten stehen Einsparungen beim Energieverbrauch und bei eventuell erforderlichen Kühlanlagen gegenüber.

SUMMARY

This article deals with proposals concerning façade constructions containing metal panels through whose sides water is circulated. The outside of the panel works as a sun collector, while the inside of the panel, constructed as a convector, transfers the absorbed sun-energy to the rooms. This system is also appropriate for cooling in summer time. Offsetting the higher costs of the facade construction are the lower expenses for heating energy and in some cases the cost of an air conditioning installation can be saved.

RÉSUMÉ

Cet article présente des éléments de façades rideaux contenant sur chacune des deux faces des panneaux métalliques remplis d'eau. Pendant la saison froide, la face extérieure sert de collecteur d'énergie solaire, tandis que la face intérieure joue le rôle de convecteur en restituant cette énergie dans le bâtiment. A l'inverse, pendant l'été, ce système peut refroidir l'intérieur. L'investissement supplémentaire doit être relativisé par les économies d'énergie et, dans certains cas, éventuellement, par la suppression de l'installation de climatisation.

1. Metallblechpaneele als Kollektor-Konvektor-Wandelemente

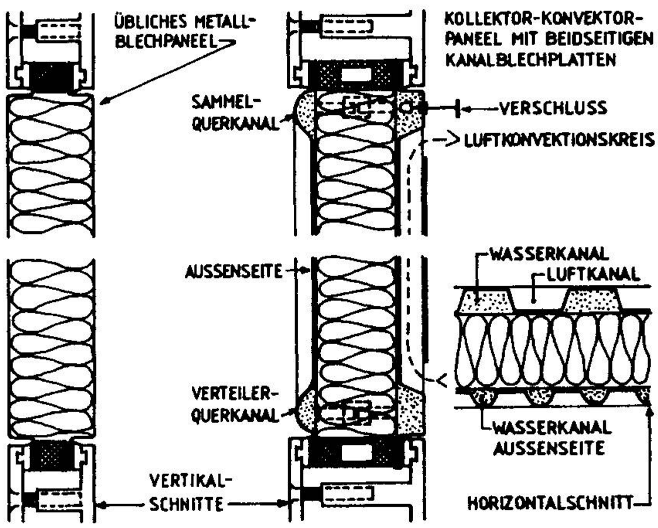
Auf Grund sinkender und teurer werdender Primärenergiereserven wie Öl, Kohle oder Gas und erhöhter Umweltbelastungen aus diesen Energieträgern durch schädliche Abgase stellt sich die Frage, in welcher Weise die vorhandene Sonnenenergie und die aus ihr abgeleiteten Energiequellen natürlicher Art besser als bisher genutzt werden können.

In diesem Zusammenhang könnte die Außenwand beispielsweise als klimatrennendes Element zwischen dem Außen- und dem Innenklima in thermischer Hinsicht nicht nur eine den Wärmefluß von innen nach außen dämmende, sondern zu gegebenen Zeiten auch eine die Wärme von außen nach innen übertragende Funktion übernehmen, denn oft sind die natürlichen Wärmequellen außen größer, als der Wärmebedarf innen. Mit der erhöhten Wärmedämmung wird leider nicht nur der Wärmeabfluß nach außen, sondern in gleichem Maße auch ein zeitweilig möglicher Wärmezufluß von außen nach innen abgedämmt. Dieser Beitrag soll deshalb in begrenztem Umfang Anregungen und Vorschläge darüber machen, wie dieses Ziel durch Verwendung beidseitig wasserdurchströmter Metallblechpaneele bei Vorhangfassaden erreicht werden könnte.

Da Metallbleche gut formbar und durch Schweißen, Löten oder Kleben gut miteinander verbindbar sind, lassen sie sich mittels bestimmter Verfahren zu Doppelblechen mit einem Kanalsystem verarbeiten, das mit einer wärme- oder kühlenergieübertragenden Flüssigkeit (z.B. Wasser mit Frostschutzmittel) durchströmt werden kann. Auf diese Weise könnte aus einer an der Außenseite liegenden Kanalblechplatte als Kollektor absorbierte Strahlungsenergie der Sonne mittels der Wärmeträgerflüssigkeit in einem natürlichen thermischen Kreislauf in eine zweite Kanalblechplatte als Konvektor an der Innenseite übertragen und von dort durch Konvektion und Strahlung an die Raumluft abgegeben werden. Bei unerwünschter Wärmezufuhr würde die Flüssigkeitsumwälzung in den oberen oder unteren Verbindungsleitungen gedrosselt bzw. unterbrochen werden können (Bild 1).

Bild 1

Schema eines Kollektor-Konvektor-Wandelementes



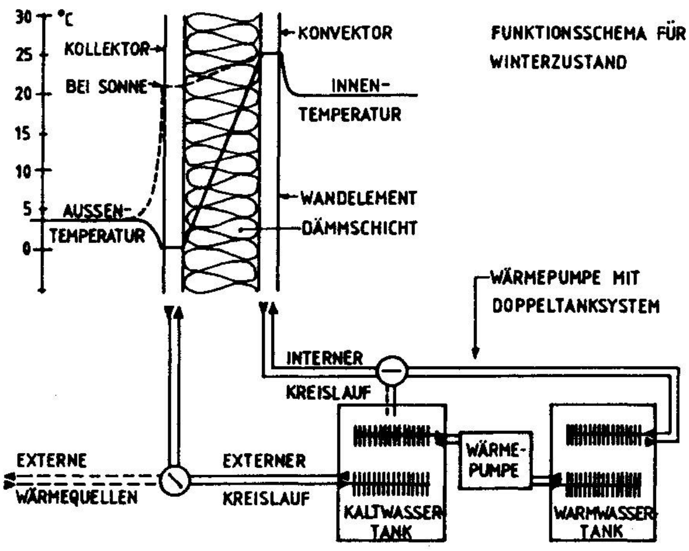
2. Wärmespeicherung und Temperaturregulierung

Mit dem einfachen Kollektor-Konvektor-Wandelement im Bild 1 läßt sich jedoch nur zur Zeit der Einstrahlung Wärmeenergie gewinnen. Bei stärkerer Einstrahlung kann vorhandene Überschußenergie ferner nicht mehr genutzt werden. Aus diesem Grunde wird statt der direkten Verbindung der beiden Kanalblechplatten zwischen dem Kollektor- und dem Konvektorelement ein wärmegedämmter Wassertank als Wärmespeicher an zentralem Ort im Gebäude zwischengeschaltet, in dem die Vorlaufleitungen der Kollektoren gesammelt die Wärmeenergie mittels Wärmetauscher abgeben können.

Um für die Raumerwärmung durch die Konvektorelemente an der Innenseite eine den jeweiligen thermischen Verhältnissen in den Räumen erforderliche Wassertemperatur zu erhalten, ist ein zweiter Tank als Warmwassertank vorgesehen worden, der von einer zwischen den beiden Tanks liegenden Wärmepumpe auf die benötigte Temperatur gebracht wird. Die Wärmepumpe entzieht an ihrer kalten Seite mit der bei ca.-2o°C liegenden Verdampferflüssigkeit Wärme mittels Wärmetauscher aus dem (aufgeladenen) Kaltwassertank und pumpt diese an ihrer bei ca.+65°C liegenden warmen Kondensorseite mittels Wärmetauscher in den Warmwassertank. Die Konvektoren können sodann über Vor- und Rücklaufleitungen mit Wärmetauschern im Warmwassertank versorgt werden. Bei fehlender Einstrahlung und niedrigen Außentemperaturen kann der externe Kreislauf statt an die Wandkollektoren auch an eine andere natürliche Wärmequelle wie Grund-, Fluß- oder Meerwasser angeschlossen werden (Bild 2).

Bild 2

Funktionsschema mit Kollektor-Konvektor-Wandelement sowie Doppeltanksystem mit Wärmepumpe



3. Möglicher Wärmegewinn im Winter

Gemäß einer Näherungsberechnung (Lit.1) können mit einem verglasten Kollektor auf der Südseite an einem klaren Wintertag im Januar (52°NB) bei einer Tages-Einstrahlungsmenge von 3.65o Wh/m^2 und einem angenommenen Nutzungsgrad der Kollektoren von 5o% (z.B. 75% Strahlendurchlaß und 25% Transmissionswärmeverlust durch Verglasung nach draußen) 1.825 Wh/m^2 Energie gewonnen werden. Bei einem fassadenmittig gelegenen und von Nachbarräumen gleicher thermischer Situation umringten Raum von 4·4·2,5 = 4o m^3 Rauminhalt und einer Außenwandfläche von 4·2,5 = 1o m^2, wovon 2 m^2 Fensterfläche und 8 m^2 Kollektorfläche, ergibt sich ein Wärmegewinn von 8·1.825 = 14.6oo Wh. Dieser Raum hat unter der Annahme einer Außenlufttemperatur im Tagesmittel von ± 0°C und einer Innentemperatur von 2o°C über Tag und 17°C über Nacht gemäß nachfolgender Wärmebilanz nur noch einen Tages-Wärmeenergiebedarf von 2.11o Wh, da das 2 m^2 große Fenster bereits viel Sonnenenergie zuführt. Der Energieüberschuß von 12.49o Wh könnte dann für die folgenden Tage im Kaltwassertank reserviert werden. Als Vergleich würde sich dabei beispielsweise 1 m^3 Wasser um 1o,7 K erwärmen.

	Winterfall a)	Winterfall b)
Wärmebilanz:	klarer Himmel	bedeckter Himmel
Lüftungswärmeverlust:	- 6.11o Wh	- 6.11o Wh
Transmissionswärmeverlust:	- 3.9oo "	- 3.9oo "
Einstrahlungsgewinn Fenster:	+ 5.11o "	+ 88o "
Interne Wärmequellen:	+ 2.79o "	+ 2.79o "
Wärmebedarf:	+ 2.11o Wh	+ 6.34o Wh

4. Möglichkeit der Raumkühlung im Sommer

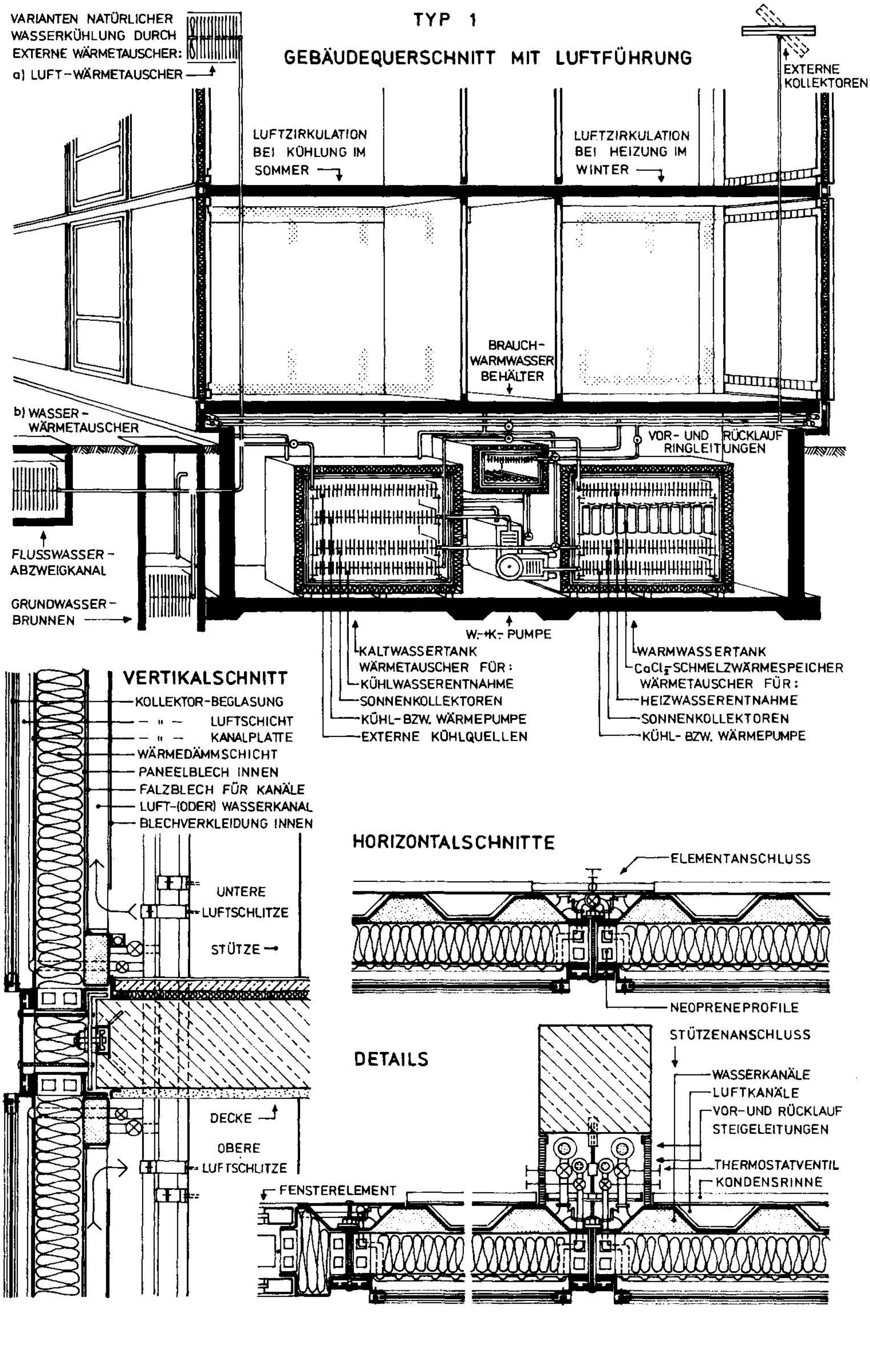
Die Konvektoren an der Innenseite sind auch als Kühlelemente an heißen Sommertagen verwendbar, wodurch sich bei kühlbedürftigen Gebäuden eine Kühlanlage in Verband mit einer Luftbehandlungsanlage ersparen läßt. In diesem Falle muß das Vor- und Rücklaufsystem der Konvektoren auf den entsprechenden Wärmetauscher im Kaltwassertank umgeschaltet werden (siehe Bild 2). Als Kühlenergiequellen für den Kaltwassertank können wieder Grund-, Fluß- oder Meerwasser in Betracht kommen. Falls diese nicht vorhanden sind, kann auch ein Luftkühler an geeigneter Stelle draußen (z.B. auf dem Dach) über Nacht den Kaltwassertank mittels kühlerer Nachtluft abkühlen. Über Tag kann dann die Wärmepumpe dem Kaltwassertank weitere Wärmeenergie entziehen und diese in den Warmwassertank für Brauchwassernutzung u.ä. pumpen, so daß der Kaltwassertank auf der für die Kühlung jeweils gewünschten Temperatur gehalten werden kann.

Eine Näherungsberechnung (Lit.1) über den täglichen Kühlenergiebedarf für den zuvor beschriebenen Raum an einem klaren Sommertag mit einer Außenlufttemperatur im Tagesmittel von +22,3°C und einer Temperaturspitze von 3o,o°C am Nachmittag ergibt unter der Voraussetzung verschatteter Fensterflächen mittels äußerer Sonnenschutzanlagen einen Bedarf von 6.895 Wh. Als Vergleich müßte dabei beispielsweise 1 m^3 Wasser um 5,9 K abgekühlt werden.

5. Konstruktionsbeispiele *)

Als Vorbilder für eine mögliche Realisierung werden nachfolgend zwei Konstruktionsbeispiele gezeigt. Bild 3 zeigt im oberen Bildteil den Querschnitt eines Gebäudes mit einer Vorhangfassade aus Kollektor-Konvektor-Metallblechpaneelen für ein Bürogebäude, bei dem das Doppeltanksystem mit Wärmepumpe im Kellergeschoß untergebracht ist. Der untere Bildteil enthält Details von den Wandelementen. Die Kollektorelemente an der Außenseite sind in diesem Falle verglast vorgesehen. In Klimagebieten mit niedrigen Außentemperaturen, aber häufigerem Sonnenschein im Winter kann eine Verglasung der Kollektoren vorteilhaft sein, weil der Wärmeabfluß von der Absorberfläche nach draußen geringer ist. In Gebieten mit mehr Bewölkung, aber nur mäßig niedrigen Außenlufttemperaturen (meist maritime Küstengebiete) kann eine Verglasung dagegen unerwünscht

Bild 3 Konstruktionsbeispiel 1



sein, weil dort die Wärme hauptsächlich der Außenluft entzogen werden muß und diese mit dem Wind unmittelbaren Zugang zu den Absorberflächen des Kollektors haben muß. Dieser Wärmeentzug ist möglich, weil der Kaltwassertank mit der niedrigen Temperatur der Wärmepumpen-Verdampferflüssigkeit unter der Außenlufttemperatur gehalten werden kann. Bei sehr niedrigen Außentemperaturen muß allerdings mit Strom oder Gas bivalent zugeheizt werden.

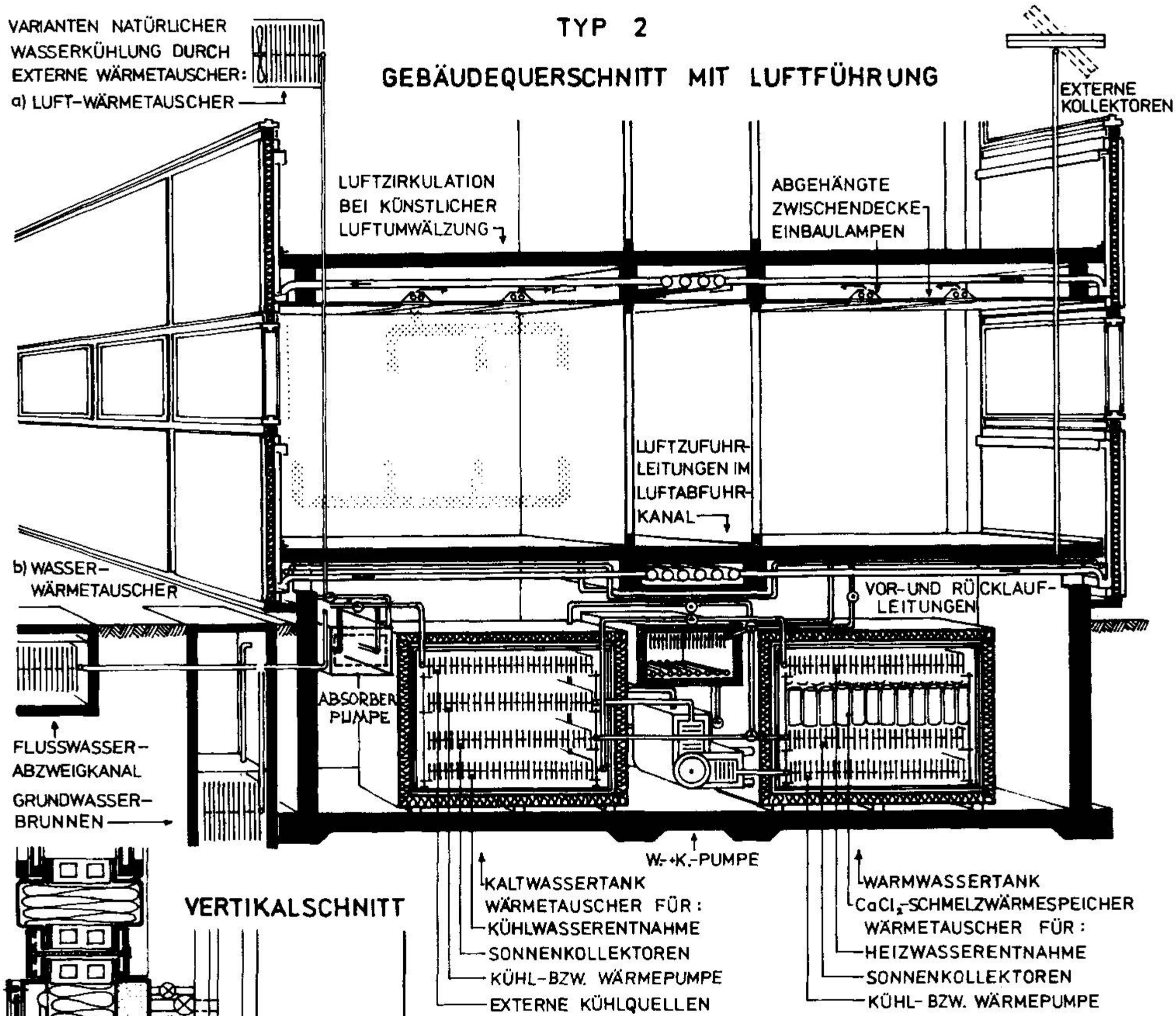
Bild 4 zeigt als zweites Beispiel eine Variante der Fassadengestaltung mit durchlaufenden Fensterbändern. Die Kollektor-Konvektor-Paneele beschränken sich auf durchlaufende Brüstungsbänder. Infolge verringerter Konvektorhöhe wird eine natürliche Luftumwälzung mittels Thermik für eine ausreichende Wärmeübertragung unzureichend sein. Aus diesem Grunde sind hier die Konvektoren unterhalb der Decke an ein Luftzufuhr-Leitungssystem angeschlossen. Sie werden, je nach gewünschter Wärmeabgabe, mit unterschiedlichen Luftgeschwindigkeiten zwangsweise durchströmt. Bei diesem Lüftungssystem kann der Abluft zugleich Wärme im Kaltwassertank entzogen und der von außen angesogenen Frischluft als Zuluft Wärme im Warmwassertank zugeführt werden. Zu diesem Zweck sind die Tanks noch mit einem luftführenden Rohrschlangensystem zu bestükken, was im Bild 4 aber nicht mehr gezeigt wird.

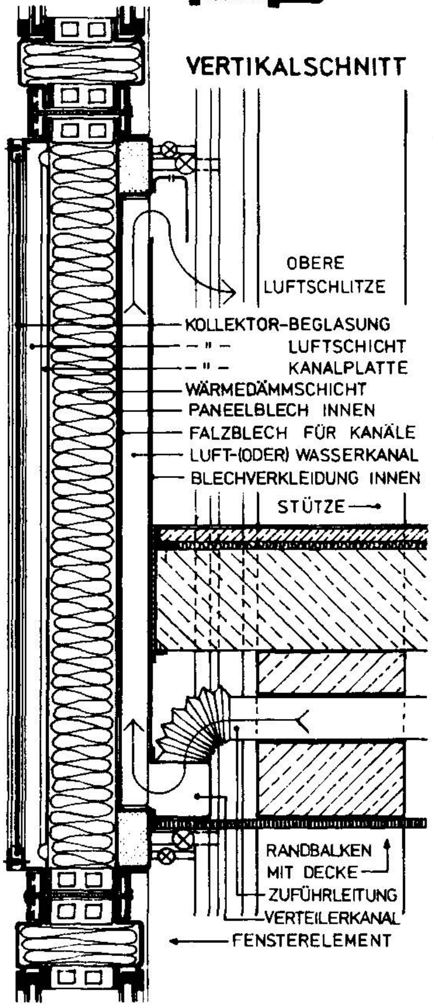
LITERATUR

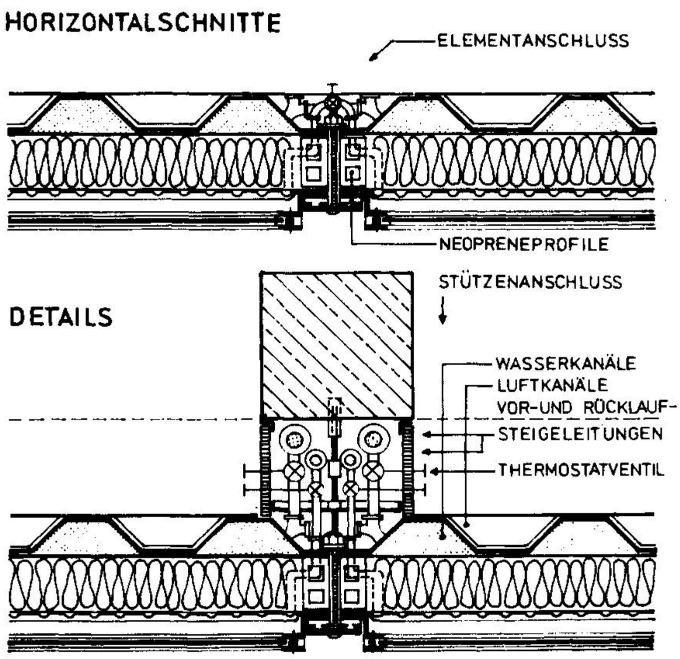
1. Haferland F., Durchströmte leichte Fassadenkonstruktionen zur natürlichen und künstlichen Regulierung des thermischen Raumklimas. Die Bautechnik, Heft 5+7/198o, Ernst & Sohn, Berlin.

*) Systeme und Konstruktionsteile sind in einigen europäischen Ländern patentrechtlich geschützt. Rechte oder Lizenzen können aber erworben werden.

Bild 4 Konstruktionsbeispiel 2





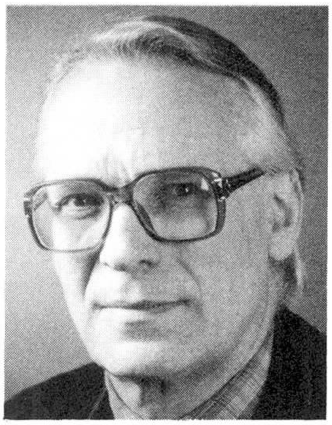


Supplementary Heat Insulation using Profiled and Coated Steel Sheet

Isolation thermique additionnelle utilisant des tôles profilées traitées

Zusätzliche Wärmeisolierung unter Verwendung von profiliertem und beschichtetem Stahlblech

Bertil FRANKLIN
Architect SAR
MAF Architektkontor AB
Luleå, Sweden



B. Franklin is a consulting architect in Luleå. He was the chief architect for the construction of the new Technical University in Luleå. He has also designed churches, officeblocks, workshops and sports centres. In 1978 he received the award «Silverbeam» from the Swedish Institute of Steel Construction for his contribution to research and development of steelbuildings.

SUMMARY

After the war many houses were built in a great hurry in Sweden. The quality was not the best. Oil was cheap and the heat insulation ineffective. These buildings now need maintenance and improved heat insulation. The most economic way is by overcladding together with supplementary heat insulation. But how do we tackle the aesthetic problem?

RÉSUMÉ

Après la deuxième guerre mondiale, il a fallu construire rapidement de nombreux logements, en Suède. La qualité de construction n'était pas des meilleures. Le mazout était alors bon marché et l'isolation négligée. Ces bâtiments nécessitent actuellement une rénovation et une amélioration thermique. La solution la plus économique consiste en l'adjonction d'un revêtement supplémentaire en tôle muni d'une isolation. Cependant, un problème se pose: comment traite-t-on l'esthétique des façades?

ZUSAMMENFASSUNG

Nach Kriegsende wurden in Schweden innert kurzer Zeit viele Häuser gebaut, die jedoch keine gute Qualität aufwiesen. Öl war billig und infolgedessen eine Wärmeisolierung weniger nötig. Diese Häuser benötigten jetzt Unterhalt und bessere Isolierung. Die wirtschaftlichste Methode ist die Einkleidung mit profilierten Stahlblechen zusammen mit einer zusätzlichen Isolierung. Doch wie kann das ästhetische Problem gelöst werden?

1. INTRODUCTION

Even in Sweden, after the war, we had a housing shortage. We built many houses quickly and the quality was certainly not the best. Oil was cheap and therefore a good heat insulation was not thought necessary. Today these buildings are in need of maintenance. They are mostly rendered and built with light concrete blocks. The most economic way to renovate the facades is by overcladding with coated profiled steel sheet combined with heat insulation.

The swedish government gives subsidies when improving the insulation of permanent dwellings. The thickness of the insulation must be at least 95 mm mineral wool or equivalent.

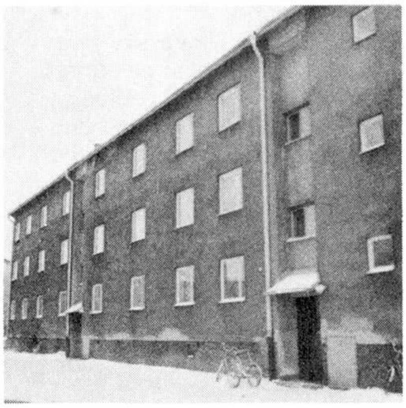


Fig. 1 Typical building from the fifties ready for renovation

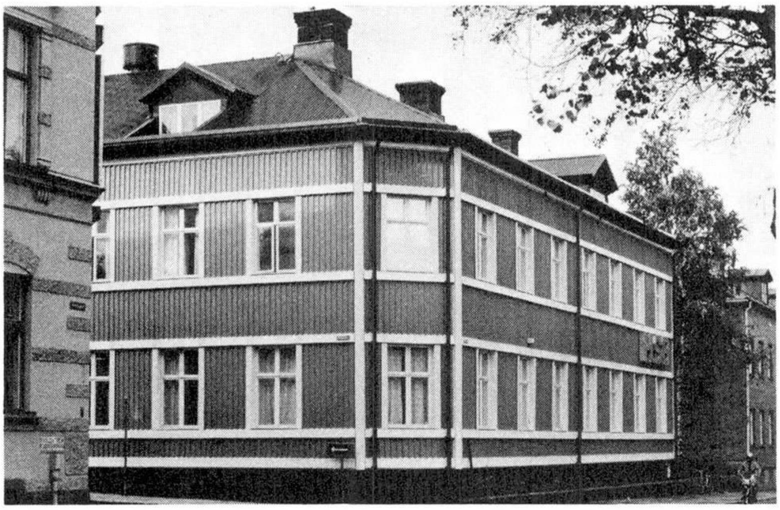


Fig. 2 The new facade must blend into the existing environment

2. ARCHITECTURAL PROBLEMS

2.1 Adaption to the surroundings

When we improve the insulation outside the wall, we change the appearance of the house. It doesn´t matter if we try to imitate the original facade or not, or which cladding material we choose. We always increase the thickness of the wall and change the relation between wall and window, wall and the eaves etc.

Before we start a facade-renovation we have to look at the surroundings. If the facade is a part of a continuous row along a street, you must be especially careful when choosing colours. It is important that the new facade blends into the existing environment and does not become a monument of its own.

If the building is located in a landscape or park, surrounded with trees and bushes, we have more freedom. We can choose a brighter colour and emphasise the building in its own right.

2.2 To renovate or change the facade

We have come to the conclusion that it isn´t possible to make an exact imitation. Instead we have to study the elements of the original facade. How are the scale and the dimensions of the elements related? We try to follow the lines and the shadows of the old facade. If we do that in an artistic way, I am convinced that it is a better way than trying to create a perfect imitation. I also believe it is the best way in an urban environment.

It is always a temptation and a challenge to make a new facade. To create a contrast. But in an urban environment it can be a disaster. In a landscape, or if we have a group of buildings, we have other conditions to consider. It is always dangerous to mix styles and colours. Therefore, it is important to have a clear plan.

2.3 Interesting renovationobjects

During the fifties and sixties in Sweden many houses of poor quality were built, both architecturally and technically. They were of three stories or multistories. The aim now must be, to improve them in both ways. Presently we have the opportunity.

2.4 Multistorey-buildings

I think these buildings are the best to renovate with steel sheet. We need fresh-looking colours. Reflections give lightness and that is what we can get from coated metal-sheet. These buildings have no old tradition and are sometimes already clad with metal-sheet.

Remember to be careful and use light colours. A failure is visible from a long distance and difficult to change.

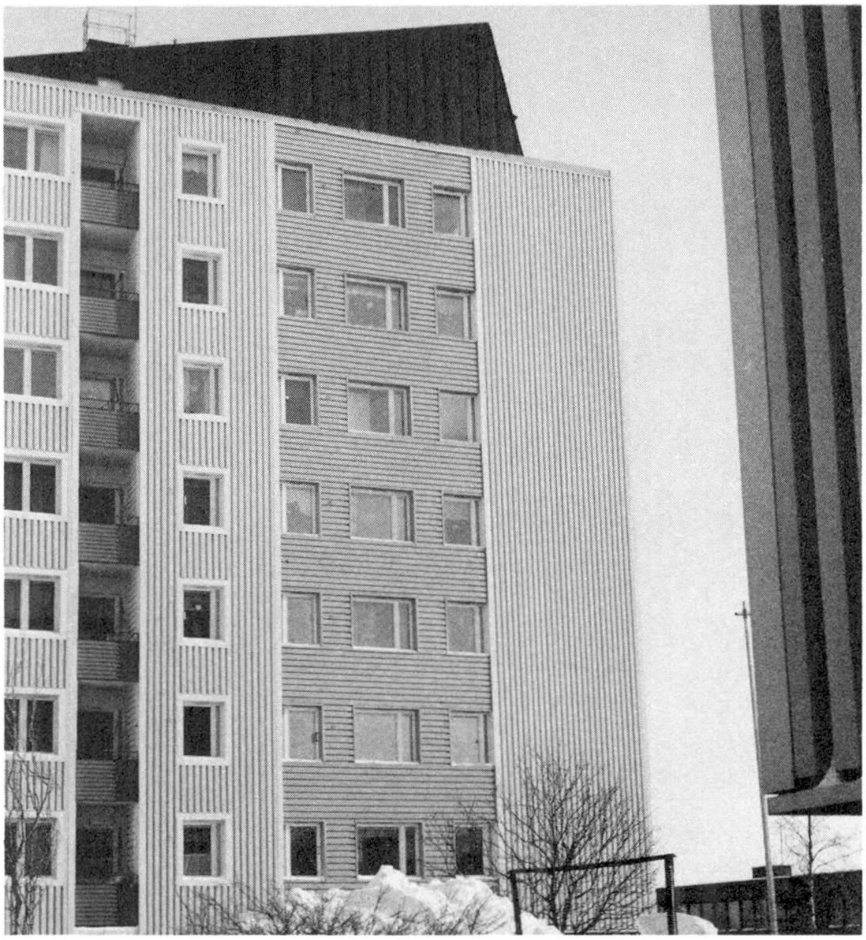


Fig. 3 High-rise-buildings are simple to renovate with steel sheet

2.5 Two or three storey houses

These houses are the most common in Sweden.

Which type of profile is best? If you want the facade to look as if it is clad with wooden boards, that is easy. Our common profiles are often asymmetric and you can apply them with the wide flange out- or inwards.

If you prefer the wooden appearance, it is important to be consistent when making the surrounds of doors and windows and the flashing of corners, etc.

2.6 One-family houses

These houses can be treated more individually and be handled more freely.

2.7 Type of profile and the direction

Profiles with the same partitions per unit look similar, even if the depth is the same.

Symmetric profiles are monotonuous compared with asymmetric.

Horizontally applied profiled sheets produce more pronounced lines than the same profiled sheet installed vertically, as most light comes from above.

The pattern of the profiling is more pronounced on horizontally applied sheets and does not disappear when viewed from a distance or at an angle.

Fig. 4 Horizontally applied profiled steel sheet gives more pronounced lines than vertically

2.8 Colour

The colour is more important than the profiling especially when viewed from a long distance. Of course, in a town, when you walk near the building, the profiling is also important.

There has been a tendency to use many strong and bright colours. To do that needs a skilful artist. It is safer to use just a few-colours and prefereably the lighter ones. My suggestions are to:

- Choose light colours rather than strong
- Use just a few colours than many
- Have the whole situation in mind and remember the neighbourhood
- Check colours with large samples
- Take advice from professionals
- Take coatings of first quality

3. TECHNICAL DETAILS

3.1 The entrance

The entrance is the most important part of the building. It should make you welcome and also reveal the owners attitude.

In living houses the surrounds of the entrance is often clad with marble or real stone. It is important to take care of these decorations and use them together with the new material. Steel sheet cladding around the entrance is easy to damage. It is better to use wood or real stone. Bricks are also useful, but the combination with profiled steel sheet is dubious due to the fact that the brick-pattern do not compliment the line-pattern of the profiling. They are similar but not similar enough.

Fig. 5 It is important to take care of the entrance, balconies etc

3.2 Balconies and bay-windows

What charactaristics of the house must we take care of? Such elements are balconies and bay-windows. Keep them and brush them up. Perhaps you can paint them in a contrasting colour.

3.3 Mouldings and joints

All joints and mouldings must be planned and sometimes used as decorative elements.

Joints can be made with

- overlap which requires exact profiling
- flashing which is more visible than overlap
- foldings which are best for the flashings´ joints

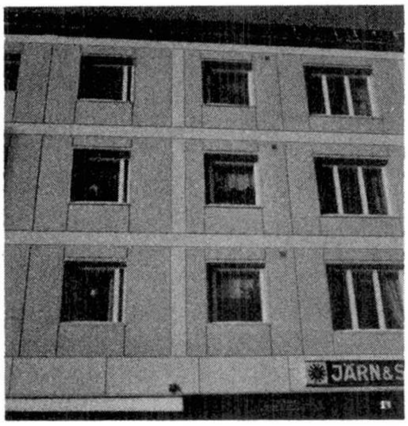


Fig. 6 Steel sheet units are similar to rendering

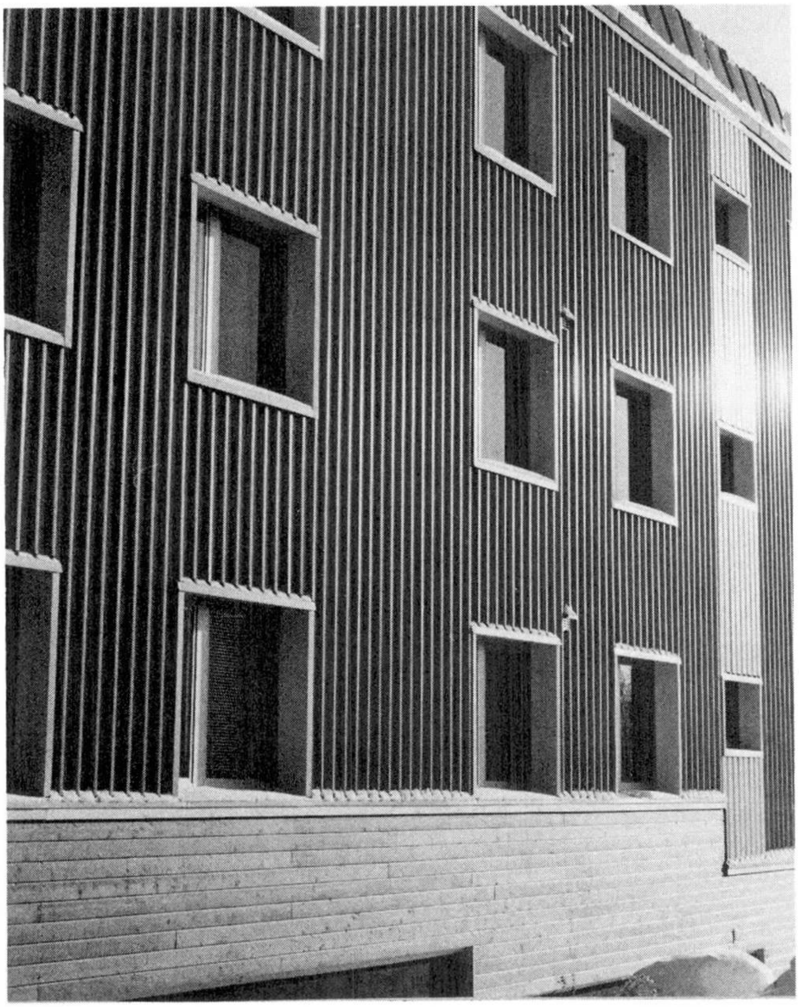


Fig. 7 A base clad with woodpanels is more resistant against damages than steel sheet

3.4 The base

Steel sheet is easy to damage and is not suitable as a base material. We can use a protection-rail of wood or metal. Even bushes can be useful.

An interesting way is by using woodpanels or the ground storey and make this element a part of the architecture.

3.5 Corner

The corner flashing can be accentuated with contrasting colour as in wood-architecture or more anonymous without contrasting colour like a rendered facade.

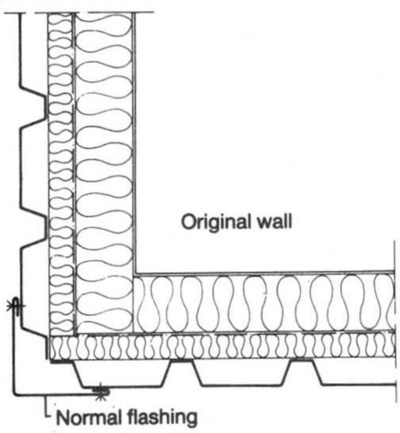


Fig. 8

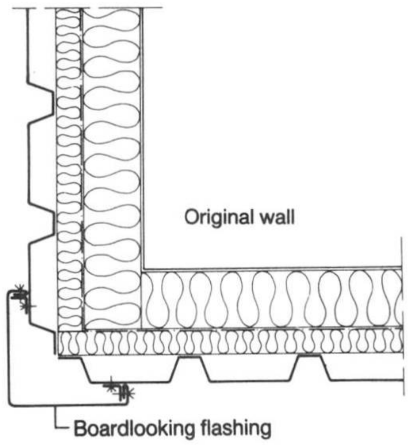


Fig. 9

With horizontal assembly the corner flashing can be the same as with vertical assembly. It can also be bevelled without flashing. But that is difficult and expensive.

The outer corner will often be damaged and need often an underlayer of wood or steel-profile.

3.6 Windows

Extra external insulation increase the thickness of the wall and the window-reveal appears deeper. Technically it is an improvement, but it can be an aesthetic problem. With white or light colour on the reveal the appearance will be improved. Even piched reveal can be used. The moulding around the window must not be too wide, preferably not more than 100 mm because of buckling.

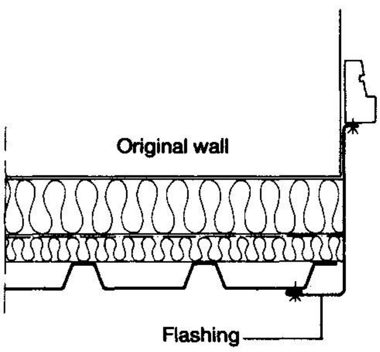


Fig. 10 Side section with normal surrounds

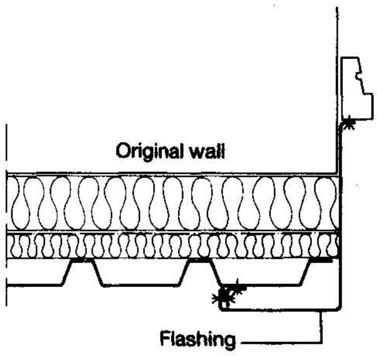


Fig. 11 Side section with boardlike surrounds

4. HEATINSULATION

4.1 Internal insulation

When the building is of historical or cultural interest and you want to preserve it, you must have the insulation internaly, because external insulation changes the appearance.

4.2 External insulation

External insulation is technically the best. Experience has revealed that the improvement is better than calculations show, depending on following criterior.

.22 Airtight walls

The improved insulation reduces the number of unintentional air changes by 0.1 - 0.3 times per hour compared with the original wall. That gives an improvement of 0.2 W/m^2 ^oC.

.23 Reduced thermal bridges

A practical improvement of 0.15 W/m^2 ^oC is possible due to the covering of the ends of the floor structure.

.24 Dryer walls

The new cladding protects the original wall from water and the insulation-ability increase.

.25 Warmer internal surfaces

Warmer internal wallsurfaces are more comfortable and lower internal air-temperature become more acceptable.

.26 Sound-proofing is improved

5. CONSTRUCTION

5.1 The condition of the original wall

It is important that the surface of the wall is smooth. Ventilated airspace behind the new insulation can take away almost the whole new insulation-effect.

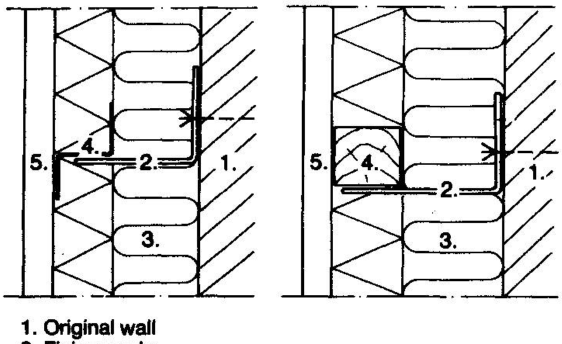
5.2 Heatinsulation

The most common material is mineral wool. It permeates the moisture and there is no risk for condensation inside the insulation. It is inflammable. The most economic thickness depends on the insulation capacity of the original wall.

To give a minimum of thermal bridges the insulation is applied with two layers. Gaps between the insulation and the cladding rails must be avoided.

The inner layer is continuous. The other is applied between rails and has lower air permeability with a papermembrane to protect against wind.

Between insulation and the cladding is a ventilated space and this is normal, when using profiled steel sheet.



1. Original wall
2. Fixing angle
3. Supplementary insulation
4. Cladding rail
5. Profiled steel sheet

Fig. 12

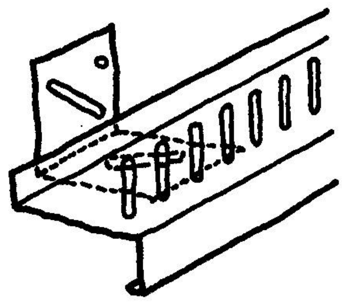


Fig. 13 Adjustable cladding rail

5.3 Cladding rails

The rail material is steel or wood. Most common are zinkcoated z-purlins. Wooden rails are not useful when fire-resistance is needed, as for instance in highrise buildings. In order to compensate for irregularities in the facade adjustable rails can be used.

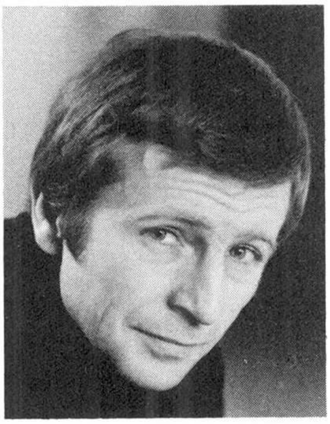
The rails are normally applied horisontally with a distance between 1.0 - 2.0 m. Normal distance for small buildings is about 1.2 m.

Windows and Curtain Walls in «High Insulation Technology»

Fenêtres et façades rideau en «Haute Isolation Thermique»

«Hochisolationstechnologie» für Fenster und Fassaden

Bruno KELLER
Dr. sc. nat.
Geilinger, Metal Works Div.
Winterthur, Switzerland



Bruno Keller, born 1942. Graduated in Physics at the Federal Institute of Technology at Zurich. Until 1984 in Research and Development, 1985 Head of High Insulation Technology Department.

Paul GRETHER
Electrical Engineer
Geilinger, Metal Works Div.
Winterthur, Switzerland

Kurt BRADER
Mechanical Engineer
Geilinger, Metal Works Div.
Winterthur, Switzerland

SUMMARY
The main features of the «High Insulation Technology» (HIT) are presented. The extremely low values of the coefficient of heat transfer for windows completely change the comfort conditions as well as the energy management: high comfort with no heating and a very economic ventilation. Results of measurements in occupied rooms and some applications in buildings presently under construction are presented.

RÉSUMÉ
Les principes de la «Haute Isolation Thermique» pour fenêtres et façades sont présentés. Les valeurs très faibles du coefficient de transmission thermique pour les fenêtres influencent beaucoup le confort et le budget énergétique d'un bâtiment: haut confort sans aucun chauffage et avec une ventilation très économique. Des mesures dans des locaux occupés et des applications pratiques dans des bâtiments en construction sont présentées.

ZUSAMMENFASSUNG
Die Prinzipien der «Hochisolationstechnologie» (HIT) für Fenster und Fassaden werden vorgestellt. Die extrem tiefen Werte der Wärmedurchgangskoeffizienten für Fenster haben weitreichende Konsequenzen sowohl für den Komfort als auch für den Energiebedarf und die Haustechnik: hoher Komfort ohne Heizung und mit einer sehr ökonomischen Lüftung. Messungen in genutzten Räumen sowie konstruktive Anwendungen an im Bau befindlichen Gebäuden werden diskutiert.

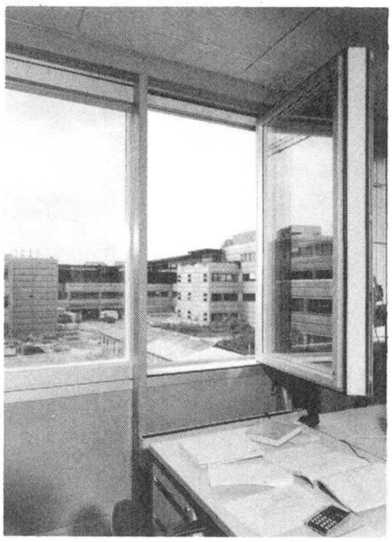
1. "HIGH INSULATION TECHNOLOGY"(HIT)

In a joint development effort since 1978, the two companies Geilinger Ltd, Metal Works Division and Sulzer Bros Ltd, Heating and Air Conditioning Division have developed a new window technology. The work started from the following facts:

- the window area and its quality determine the maximum loads both for heating and for cooling except for the internal loads: the power amplitude,
- the low surface temperatures of common glazings require local comfort compensations to avoid draught, thus fixing the positions of the HVAC-installations
- the attainable range of humidity is restricted by the thermal bridges in common windows leading to condensation (1)

The aim was therefore,

- to eliminate all thermal bridges,
- to improve the U-value of the glazing to values much below 1 W/m2K
- to improve the U-value of the frame to a level adequate to that of the glazing,
- to make a wide range of shading coefficients available.



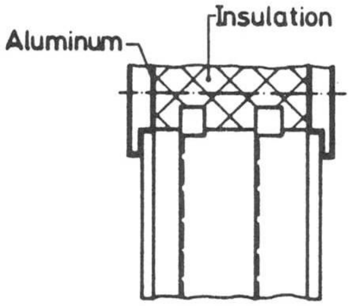


Fig 1 Schematic cross-section through HIT-window: frame (above), glazing (below)

Fig 2 View through HIT-window at Federal Institute of Technology, Lausanne (left)

The result is (figure 1 and 2):

- a glazing with U-values between 0.5 and 0.7 W/m K, shading coefficients from .2 to .56 and luminous transmittances from 0.3 to 0.63,
- a frame with a U-value of 1 W/m2K
- the absence of all thermal bridges (figure 3)
- a window with a sound transmission of 44 to 45 dBA.

The glazing has a thickness of 100 mm and consists of two glass panes separated by an air gap of 90 mm. The air gap is divided by two suspended polyester films, which have a heat mirror coating. By variation of the type of coating (3 types) and including coated or tinted glass, a very wide range of shading coefficients can be attained.

The frame consists of aluminium parts separated by a thick (80 mm) insulating zone. The frame acts itself as sealing for the glazing and forms thus an

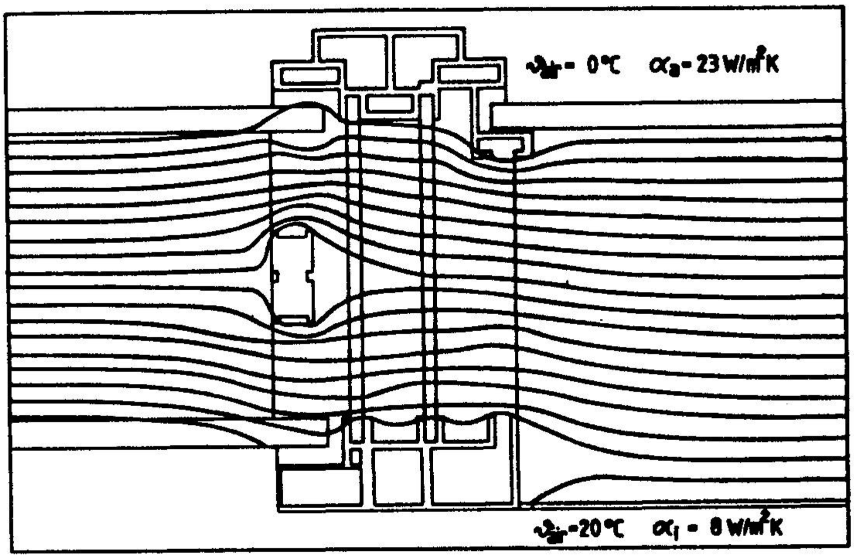


Fig 3 Temperature-distribution in HIT-frame and -glazing. Isotherms $\Delta\vartheta = 1^{o}C$. Left: glazing, middle: frame, right: curtain wall

integrated window unit without a separate sealing. The large air gap is vented to the outside to avoid pressure differences. This is done through a replaceable filter, yielding a high robustness and repairability.

Such windows have been tested at the test house LESO of the Swiss Federal Institute of Technology at Lausanne (2) for more then two years and even on the Jungfraujoch at 3500 m above sea level under the guidance of the Swiss Federal Institute for Material Testing with best results:

U-value measured: 0.68±0.06 W/m2K calculated: 0.65 W/m2K
Loss factor of 22 m2 facade with 9m2 of glazing:
HIT : measured 14.9±2.5 W/K calc:13.7 W/K
Reference triple glazing: measured 36.6±6.0 W/K calc:35.4 W/K

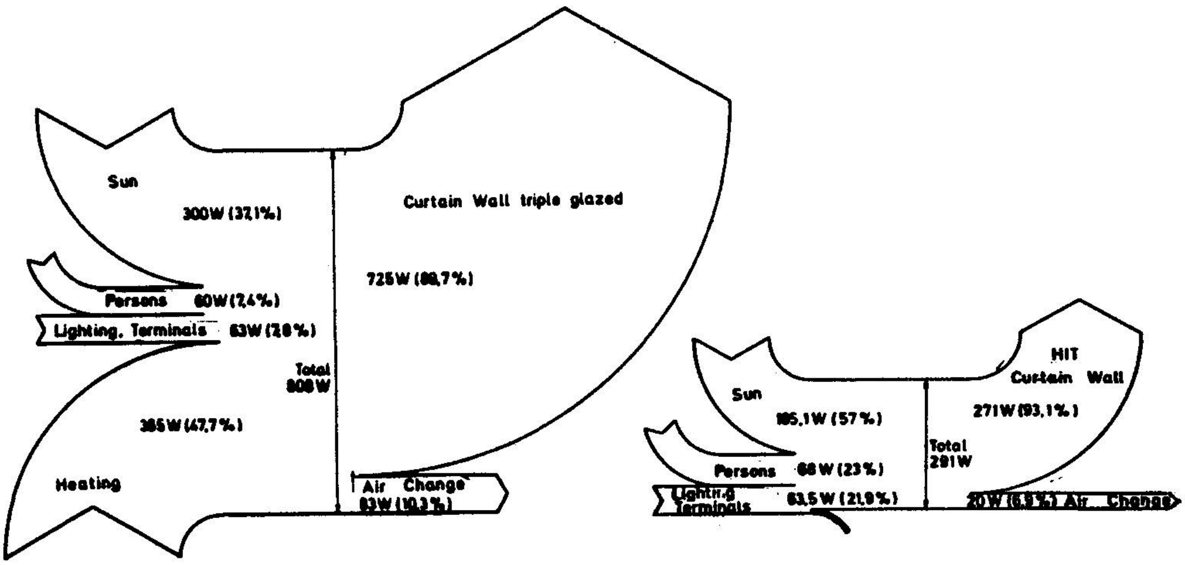


Fig 4 Mean power flux through curtain wall with triple glazing (left) and with HIT-window (right). Time: One week, $\vartheta_{ext} = 1.6^{o}C$, $\bar{I}_s = 98$ W/m2

Figure 4 shows the measured energy flux diagram of the HIT and of the reference room for a representative mean winter week:
$\bar{\vartheta}_{ext}$ = 1.6°C and $\bar{I}_S$ = 98.5 W/m2.
There are three striking features:
- the total turnover of energy is very much reduced: 291 W compared to 808 W,
- the solar gain and the internal sources cover all losses: transmission and air leakage for HIT but by far not for the reference room,
- although the solar gain for HIT is in absolute values much smaller (165 W compared to 300 W) the relativ portion is much bigger (57% compared to 37%) because of the very much reduced losses.

2. COMFORT

Figure 5 shows measured surface and air temperatures near the window without any heating. As expected, the surface temperature of the glazing remains for HIT very near to the mean air temperature even for low external air temperatures: ϑ_{ext}=-10 C, $\Delta\vartheta$= 3 C. Discomfort due to asymmetric radiation loss is therefore eliminated independent of the size of the window and the distance to it.

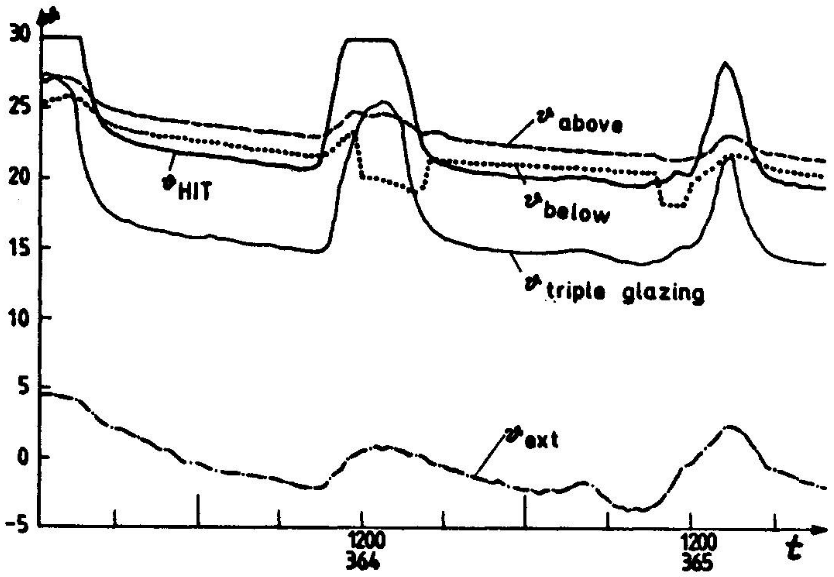


Fig 5 Surface temperatures on HIT- and triple glazing without heating, air temperatures above and below the window.

Extensive measurements of the flow pattern in the room and near the window surface have been made with low velocity anemometers(3).

In table 1, we present some measured values for HIT, triple and double insulating glazings and computed values for extreme conditions: ϑ_{ext}=-10° C, window height h = 2m.

In fact, the people working in the HIT rooms did not feel any discomfort even with no heaters below the window.

We have therefore put the heater in the worst position on the rear side of the rooms. But even then, no discomfort was felt. We thus conclude, that cold air draught is sufficiently reduced as to free the HVAC-equipment from local fixations.

Table 1. Measured and computed air velocities in boundary layer.

Glazing:	Measured for ϑ_i = 21°C, ϑ_{ext} = -2°C, h = 1.6m	Computed for ϑ_i = 20°C, ϑ_{ext} = -10 C, h = 2 m(4)
HIT	v= 12 cm/s $\Delta\vartheta$= 2.4°C	vmax = 24 cm/s $\Delta\vartheta$= 3°C
Triple	v= 16 cm/s $\Delta\vartheta$= 5.5°C	vmax = 40 cm/s $\Delta\vartheta$ = 8°C
Double	v= 19 cm/s $\Delta\vartheta$ = 7. °C	vmax = 48 cm/s $\Delta\vartheta$=11°C

3. CONSEQUENCES FOR THE HVAC-EQUIPMENT

During operating time, the internal sources: men, terminals, lighting and/or solar irradiation compensate for all transmission losses of HIT-equipped rooms even at design temperatures.
The measured time constant τ of such rooms:

$$\Delta\vartheta(t) = \Delta\vartheta(0)\cdot e^{-t/\tau}$$

τ: Time constant = C / L
C : Thermal storage capacity [MJ/K] L: Loss Factor [W/K]

turns out to be very big because of the small loss factor (measured at LESO: 23 days, calculated: 20 days(3)). Therefore the cooling process over night or week end is so slow, that no heating is required during the night: $\Delta\vartheta \leq 1$°C and even mostly not for the week end. Switching on the lights on monday morning suffices for an agreeable indoor climate.

For winter one has therefore no more need for heating, feeding fresh air at ambient temperature 20 to 22 C is sufficient.

In summer, the shading coefficient reduces the solar load and this can be further improved by external shades. In addition, the low U-value protects from the hot external air and the internal surface temperature is kept well below that of conventional sun protection glazings. The peak cooling power is therefore much reduced and mainly determined by the internal loads. Depending on climate and comfort requirements one may even eliminate active cooling and only work with free and night cooling.

The only remaining power need is therefore mainly that for preparing the fresh air. This fresh air is at least in winter freed from energy transportation (5). The only task is the maintaining of hygienic conditions. To reach that goal with the smallest possible amount of fresh air, a new ventilation method by stratification and displacement (6) has been developed together with the Norwegian Institute of Technology. This method allows to work with very low air change rates. It works best together with a building shell that produces only very small temperature differences as it is done by HIT-elements. Some preliminary measurements at the Norwegian Institute of Technology for HIT-conditions yielded very promising results. A complete report will be published later.

4. BUILDINGS IN "HIGH INSULATION TECHNOLOGY"(HIT)

A first building is now finished at Geneva, the "Tour Balexert". It has about 32'000 m3 volume and very large windows from the ceiling to the floor. There is no more heating near the window (Figure 6). The rooms are only supplied with fresh air at ambient temperature without any heating. Because of the lack of external shades, a somewhat higher air change rate has to be applied for cooling reasons, thus not exploiting the full potential of HIT.
A further office building is under construction at Winterthur, where the above mentioned new ventilation technology is applied in some rooms for real-life test purposes.

Fig 6 Building "Tour Balexert" at Geneva. All windows and curtain wall in "High Insulation Technology". No heating, only ventilation at 20-22^{o}C.

A wide variety of designs are now available: from curtain walls with or without casements (figure 7 and 8) to windows to be put into brick-block walls where the insulation zone is continued through the well insulating HIT-window (figure 9)

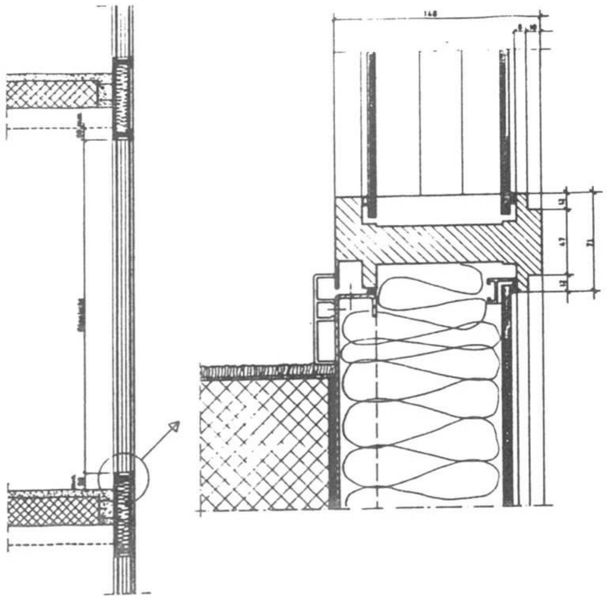


Fig 7 Example of a curtain wall with large HIT-windows.

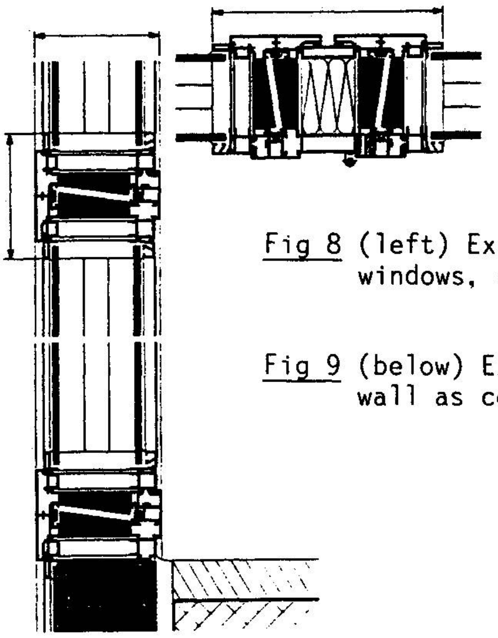
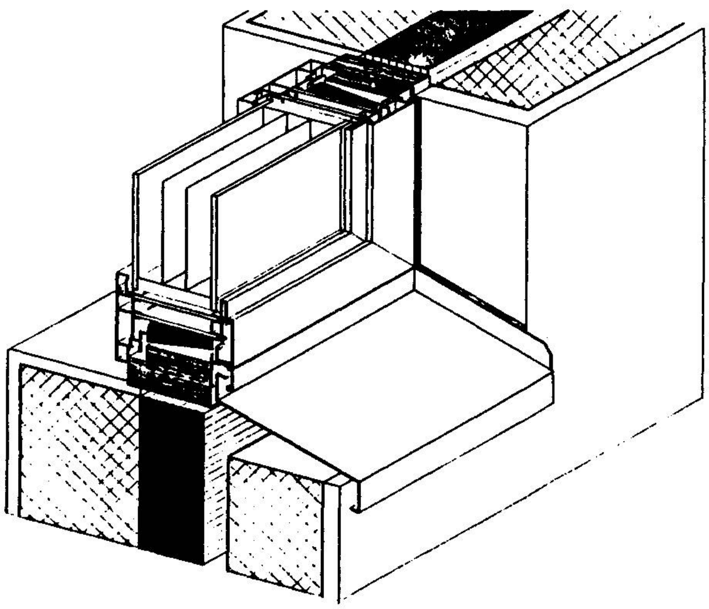


Fig 8 (left) Example for curtain wall with HIT-windows, casements.

Fig 9 (below) Example of HIT-window in brick-block wall as continuation of insulating zone.



5. CONCLUSIONS

The HIT-windows permit a HVAC-equipment focusing on the hygienic instead of the thermal requirements. Heating becomes unnecessary and cooling power is much reduced, sometimes even avoidable.

For the future, the "High Insulation Technology"(HIT) together with the ventilation by stratification and displacement promises a real step forward to a better comfort in winter as well as in summer with small air changes between

0.5 and 3 h-1 (cooling). Some buildings of that type are now under construction.

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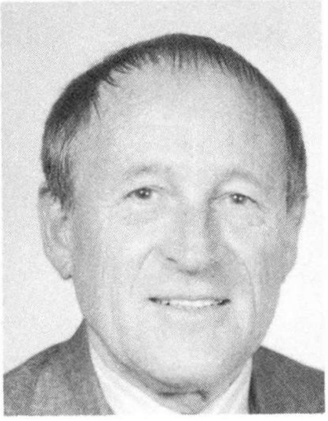
Detailing of Weathering Steel Facades

Détails des façades en acier patinable

Konstruktive Ausbildung von Fassaden aus wetterfesten Baustählen

Sven E. THOMASEN
Consultant
Wiss, Janney, Elstner Assoc.
Emeryville, CA, USA



Sven Thomasen has a structural engineering degree from the Technical University of Denmark. While with WJE, he has investigated building failures and material deterioration. He has taught at California Polytechnic in San Luis Obispo and has designed many large projects while associated with the architects, Skidmore, Owings and Merrill.

Carolyn S. EWART
Project Engineer
Wiss, Janney, Elstner Assoc.
Emeryville, CA, USA

Carolyn Ewart received a BS in Architectural Engineering from California Polytechnic State University, San Luis Obispo, and a MS in Structural Engineering from University of California, Berkeley. She has done field investigations and analysis of structural failures and evaluation and rehabilitation of masonry, stone, concrete and steel façades.

SUMMARY

The success of weathering steel façades depends on the selection of appropriate materials, consideration of the environmental exposure, and proper detailing of the cladding. Samples of successful installations are compared with details of failed weathering steel façades. These failures were caused by environmental exposure and improper detailing, and include glass breakage, accelerated corrosion of damp sections, and disintegration from expansion of corrosion products. Guidelines for the proper detailing of weathering steel are presented.

RÉSUMÉ

Le succès des façades en acier patinable dépend de la sélection des matériaux appropriés, de la prise en considération des conditions d'environnement et d'une grande précision dans la conception de la construction. Des exemples d'installations réussies sont comparés avec des installations où les détails montrent des défauts. Ces défauts étaient causés par les conditions d'environnement et par une mauvaise conception des détails. Le résultat de ces défauts est, par exemple, le bris des vitres, une corrosion accélérée des parties humides, et la destruction due a l'expansion des produits de la corrosion. Des exemples pour une bonne conception des constructions en acier patinable sont présentés.

ZUSAMMENFASSUNG

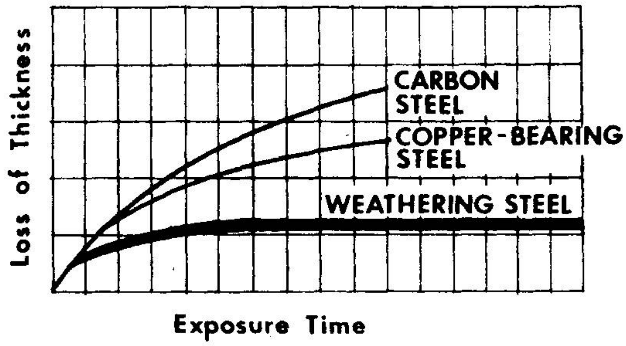
Der Erfolg von wetterfesten Stahlfassaden hängt von der Wahl des geeigneten Materials, der Berücksichtigung der Umwelteinflüsse und von der sachgemässen Wahl der konstruktiven Details ab. Beispiele erfolgreicher Ausführungen werden mit Fällen von schadhaften, wetterfesten Stahlfassaden verglichen. Diese Schäden wurden durch Umwelteinflüsse sowie durch ungeeignete Konstruktionsdetails verursacht und beinhalten Glasbruch, beschleunigte Korrosion in feuchten Bereichen und Zersetzung durch Ausbreitung der Korrosionsrückstände. Richtlinien für geeignete, konstruktive Details aus wetterfestem Stahl werden aufgezeigt.

1. INTRODUCTION

When weathering steel was first introduced to the building industry in the 1960's, it seemed to be an ideal material for bridges, structures and building facades. The steel is left unpainted, and when exposed to the atmosphere, it develops an oxide coating which inhibits further corrosion. Even though the initial cost of weathering steel was higher than plain carbon steel, the potential for substantial savings in painting and maintenance costs convinced architects and engineers to use the product. After two decades of using weathering steel, some very successful buildings have been constructed and some failures have raised serious questions about the future of the material. Architects and designers must understand the characteristics of weathering steel and follow a few guidelines in the design of weathering steel buildings in order to use the material to its fullest potential and to avoid disastrous failures.

1.1 Background

The first low-alloy steels were developed in the 1930's to meet the demand for a high-strength steel. Small amounts of chromium, nickel, copper, and other alloys were used to produce the high strength. When long-term exposure tests were conducted, it was found that these low alloy or weathering steels had four to six times the corrosion resistance of plain carbon steel.



CORROSION RESISTANCE OF WEATHERING STEEL

The initial appearance of weathering steel is similar to carbon steel, but the color and texture of the rust film which forms are very different. The rust on carbon steel is orangish brown, porous and voluminous. The rust formed on weathering steel is a thin, fine-grained film which undergoes a color change as it weathers from orange-brown to a dark brown or warm purple-black. The longer the steel is exposed, the more durable the oxide coating, or patina, becomes. For the patina to form, the steel must be exposed to alternating wet and dry cycles. In an industrial atmosphere, tests show the patina will form and the corrosion rate will decrease to insignificant levels after two to four years[1].

For many years, the primary use of weathering steel was in railroad cars, transmission towers and other industrial applications. The first major architectural use of weathering steel was in 1961 when Eero Saarinen and Associates designed the John Deere Office Building in Moline, Illinois. This seven-story structure has an exposed, unpainted exterior facade of weathering steel. The innovative use of a new material and Eero Saarinen's reputation gave the building considerable publicity. Other buildings were soon constructed with exposed weathering steel, including the Chicago Civic Center and the U. S. Steel Building in Pittsburgh.

The performance of weathering steel buildings has been inconsistent. The weathering steel on the Deere Building has performed well and the same material was chosen for an addition constructed in 1978[2]. By contrast, inappropriate detailing of other weathering steel buildings resulted in failure of the exterior facade and portions of the wall had to be removed or rebuilt. In 1980, the State of Michigan imposed a ban on the use of unpainted weathering steel for bridges after finding excessive corrosion and determining that the corrosion rate of some weathering steel was not tapering off. A later study of 49 weathering steel bridges by the American Iron and Steel Institute found that when excessive corrosion occurred it was located at areas of high chloride concentration or continuous wetting[3].

2. FACTORS AFFECTING WEATHERING STEEL PERFORMANCE

The characteristics of weathering steel must be understood in order to achieve its desired qualities and to avoid problems. The performance of weathering steel in building facades is dependent on three factors: the composition and handling of the material, the environment, and most importantly, the design and detailing of the building.

2.1 Material

The alloy composition of the steel affects its corrosion resistance and weathering characteristics. The low alloy steels with superior corrosion resistance, known as "weathering steels," are sold in the United States under the brand names "Cor-Ten" and "Mayari R" and are available from a number of steel producers worldwide. Weathering steels produced in the United States are generally specified under ASTM Standards A 242 or A 588. The standards specify the required yield strength and corrosion resistance and leave the composition of the steel up to the manufacturer. The user should consult the steel producers on the applicability of a particular steel composition and the specific brand names should be specified[4]. When in doubt about the suitability of a particular steel, exposure tests can be made at the building site. Compatible weathering steel bolts and welding electrodes should be used for unpainted connections.

The early appearance of weathering steel depends on its surface preparation and handling during construction. To achieve a uniformly weathered appearance, all exposed steel should be blast-cleaned or pickled to remove mill scale. During erection, the steel should be handled as a finish material and marks with oil, chalk, or paint should be avoided.

2.2 Environment

The development of the oxide coating on a particular weathering steel has long been recognized as depending on time, degree of exposure, and the environment. Long-term corrosion tests of weathering steels have been performed since the 1930's. The testing programs were generally designed to measure the amount of corrosion of steels of various alloy compositions. Steel samples were exposed to different environments and the rate of corrosion in terms of weight loss was measured at periodic intervals. Before a user relies on these test results, it should be verified that the environment and material used in the test are the same as those for the planned building.

On-site exposure tests were performed at some early weathering steel building sites, such as the John Deere Building. Exposure of steel samples for two or three years cannot predict the final appearance of the building, but it can reveal applications which are totally inappropriate. The effect of the environment on the corrosion is so important that some experts recommend on-site corrosion testing of weathering steels before use in any environment. Great differences in corrosivity have been found at locations only a few miles apart.

Steel producers suggest weathering steel is appropriate for most atmospheric environments: urban, suburban, rural, moderate industrial, and moderate marine. Faster weathering is promoted by moderate marine and moderate industrial environments compared to rural environments. Weathering steels are not recommended for use in severe marine environments. Soluable chloride salts present in marine environments prevent the formation of the stable, protective oxide coating. Weathering steel should not be used in industrial environments with corrosive fumes.

2.3 Design

The unique properties of weathering steel must be understood to design a successful weathering steel facade. The most important design consideration is to avoid prolonged contact of the steel with moisture. A constantly wet weathering steel surface will not form a protective patina and will corrode at an unacceptably high rate. The sources of moisture to consider are not only rain and snow, but also condensation, wet soil or moist plants, and chemical solutions used for window cleaning. The water on the facade should be shed quickly and evenly since exposure to varying quantities of water causes uneven weathering and streaking patterns on the steel. At areas of extensive runoff, the water can be collected in gutters and piped away. Weathering steel gutters should be protected on the inside where accumulated dirt and debris keep the steel wet for prolonged periods.

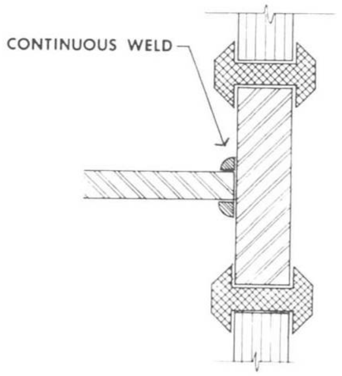
The direction of exposure of the steel and the degree of sheltering affect the corrosion rate[5]. Sheltered locations, which include not only areas under roofs and overhangs but also undersides of beams or leeward sides of columns, should ideally be avoided since sheltered steel will weather with a different color and texture at a slower rate. The bright orange color typical of the start of the weathering process can often be seen for years in sheltered locations, while nearby, the boldly exposed steel has attained its final purplish patina.

3. DETAILING WEATHERING STEEL

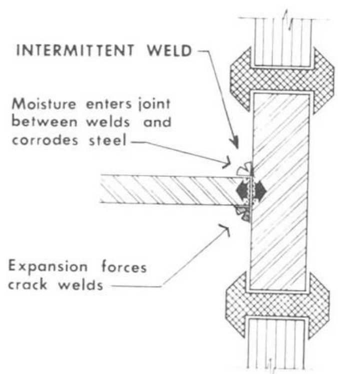
The properly detailed weathering steel facade exposes all steel surfaces to wet/dry cycles and avoids both sheltered areas and areas of constant wetness.

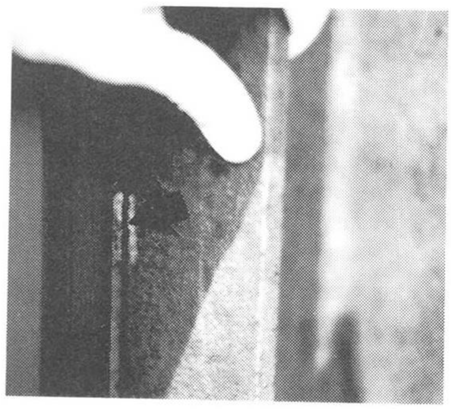
3.1 Faying Surfaces

All faying surfaces and crevices should be sealed in order to prevent moisture from penetrating and keeping the surfaces wet for a prolonged time. It is generally not sufficient to rely on bolts or intermittent welds to keep joints watertight. Unprotected faying surfaces and crevices will corrode and the corrosion products will tend to widen rather than to seal the joint. The formation of corrosion products exerts a high pressure which can break bolts and welds. Joints which are bolted or connected with intermittent welds should be protected with sealant and the faying surfaces should be painted.



RIGHT: Protected Faying Surfaces.



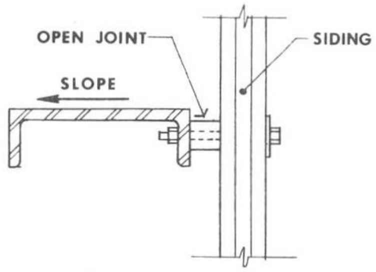


WRONG: Unprotected Faying Surfaces Result in Broken Welds.

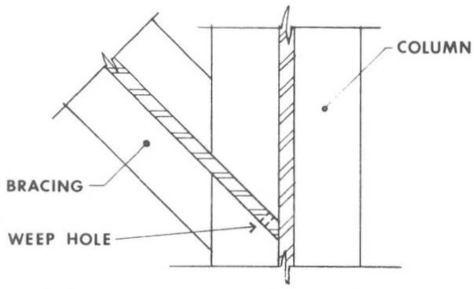
3.2 Non-Draining Surfaces

Ledges and steel surfaces should drain and areas where water can collect should be avoided. Where horizontal ledges or non-draining surfaces are unavoidable, the water can often be drained by weep holes. These holes should be of ample size to avoid clogging by rust or debris. If the surfaces are continuously wet, the steel in the affected area must be painted.

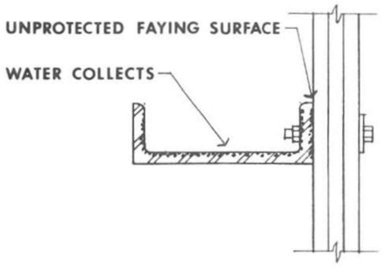
Horizontal girts for steel siding should be installed with flanges pointed down and with an open joint between the girt and the siding.



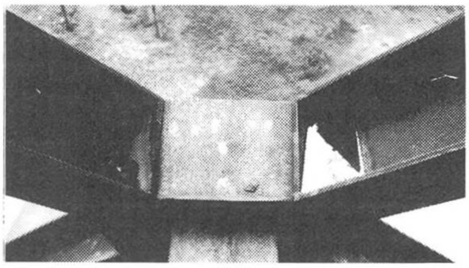
RIGHT: Horizontal Girt at Siding



RIGHT: Column Connection with Weep Hole



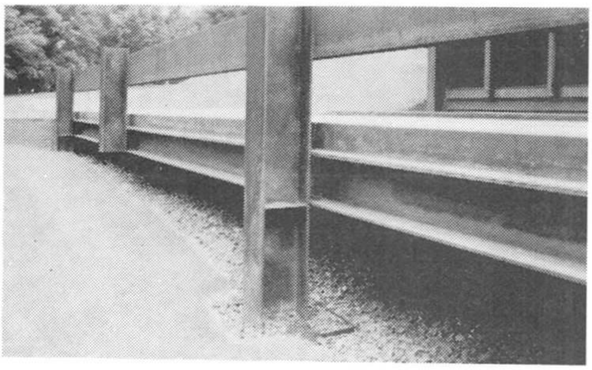
WRONG: Girt Collects Water, Unprotected Faying Surface



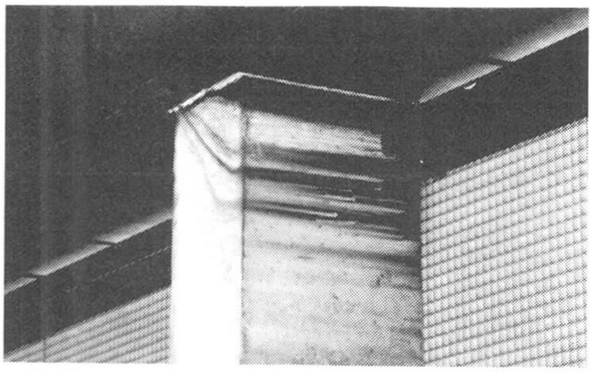
WRONG: Water Trapped in Cross Bracing Connection

3.3 Adjacent Materials

During the formation of the patina, the outer 2 - 3 mils of the weathering steel corrodes. The weathering process takes at least 2 - 3 years, but it can continue indefinitely at sheltered exposures or in rural environments. The soluable iron particles produced during weathering can cause staining and damage to adjacent materials and provisions must be made in the design to handle rust-laden runoff water. The runoff can sometimes be collected by gutters installed on the facade or overhangs and special flashings can protect walkways, parked cars, or other building elements. The visual effect of staining can be minimized by using materials with a rust brown color in areas of runoff such as colored concrete sidewalks or gravel strips.



RIGHT: Broken Gravel at Base of Column



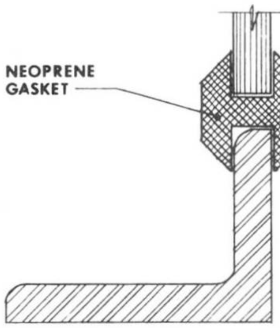
WRONG: Stain on Light Colored Concrete Column

Weathering steel in contact with other materials should be detailed not only to avoid staining, but also to avoid prolonged wetness at the contact surfaces. Steel in contact with concrete or masonry should be coated and the joint protected. Rusting of embedded weathering steel can cause cracking and spalling of surrounding concrete or masonry.

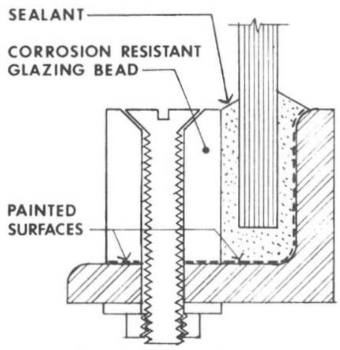
3.4 Glass Installation

The windows should be installed to avoid runoff from flowing onto glass surfaces. The windows can be recessed or drip flashings installed at the head. Only mild cleaning agents should be used for removal of rust and dirt from the glass and acid solutions must be avoided. All cleaning agents should immediately be rinsed off with clean water to prevent discoloration of the steel.

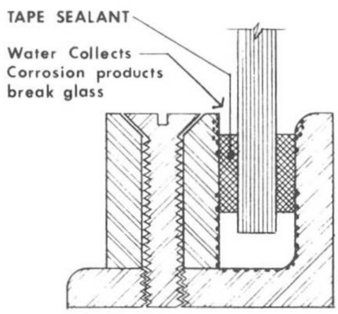
Fastening of the glass to the weathering steel frame should be designed to avoid trapping water which will result in glass breakage from expanding corrosion products. Neoprene gaskets or similar flexible material should separate the glass from direct contact with the steel.



RIGHT: Glass Installed in Neoprene Gasket



RIGHT: Corrosion Resistant Materials

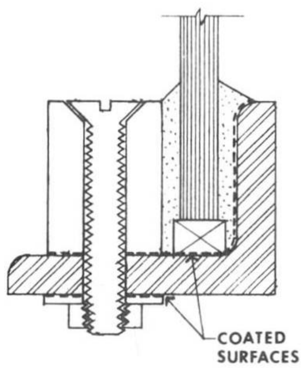


WRONG: Rust Expansion Breaks Glass

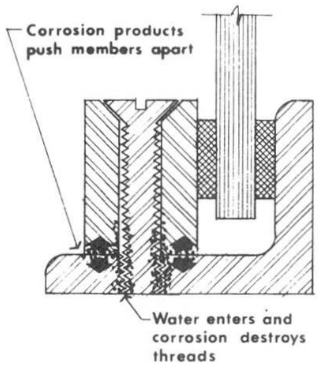
3.5 Joint Design

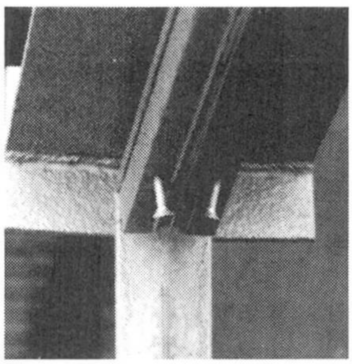
Weathering steel can be assembled by welding and special electrodes are available which provide the strength and the appearance of the base metal. The welded joints should be watertight and intermittent welding must be avoided unless the joints are sealed.

Machine bolts, high strength structural bolts, and various screws are all available in weathering steel material. Neither bolts nor screws will provide a watertight connection and the joint should be protected with sealant and the faying surfaces painted.



RIGHT: Paint Weathering Steel Faying Surfaces

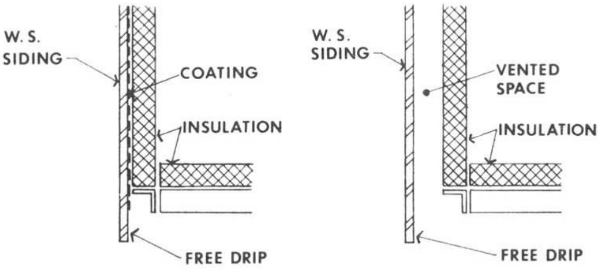




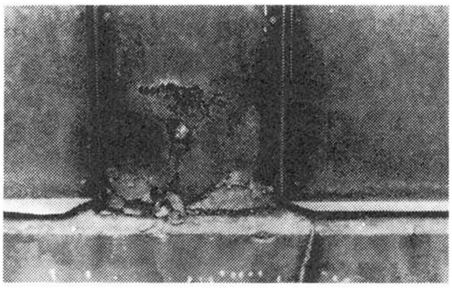
WRONG: Faying Surfaces Corrode, Screws Fall Out of Glazing Bar

3.6 Siding, Fascia, and Roofing Applications

The minimum thickness of weathering steel sheets should generally be greater than thicknesses normally used for coated sheets and not less than 0.0478 inch. The designer should consider that condensation often occurs on the inside surfaces of wall siding and roofing sheets as a result of high relative humidity within a building. Special problems arise when moisture collects in insulation placed directly against the steel sheets. To avoid corrosion, the interior face of the steel should be painted or a vented space provided between steel and insulation. Free drainage should be provided at the base of vertical siding and prolonged wetness both on the exterior, and especially on the interior face, should be avoided. The siding should terminate well above grade to avoid contact with snow or wet soil.

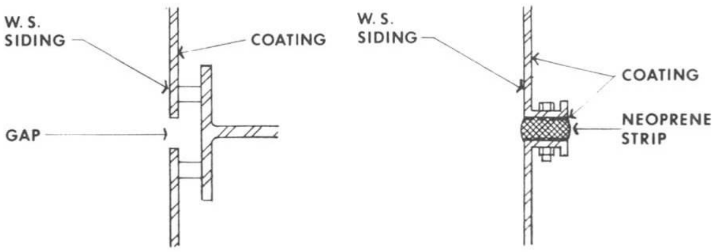


RIGHT: Interior of Siding Sheet Coated or Vented, Free Drip at Base

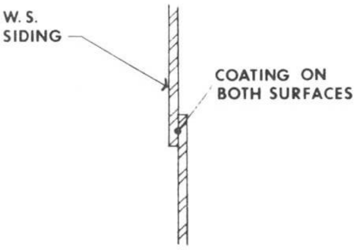


WRONG: Insulation Directly Against Uncoated Surface

External crevices such as butted joints in walls or overlapping joints in roofs require special consideration. Problems with vertical butt joints can be avoided by, instead, providing a gap or by caulking the joints. Lapped joints should be sealed and the surfaces coated.



RIGHT: Siding Butt Joints



RIGHT: Siding Lap Joint

4. CONCLUSION

Unpainted weathering steel with proper alloy composition in the right environment will develop a protective patina when exposed to alternating wet/dry cycles. The detailing of all exterior wall elements and connections must avoid creating pockets, crevices and faying surfaces where water can collect. Care must be taken in the selection and detailing of adjacent materials in order to avoid rust staining or deterioration. The unique properties of weathering steel make it a challenging material to use in designing a building facade. Properly exposed weathering steel has a textural and color variation common in natural materials. It is an appropriate material for building facades when the characteristics of the steel are considered in the design.

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5. "Cor-Ten Steel, Corrosion Resistant Steel", Architectural and Engineering News, February, 1965.
6. Mayari R Weathering Steel, Bethlehem Steel, July, 1971.