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INSULATION AND AIR SEALING: CURRENT AND EMERGING TRENDS IN EUROPEAN MASONRY BUILDINGS

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ABSTRACT

Across the world, the dominant form of building construction is heavy, load-bearing masonry or poured concrete, not timber- or steel-frame. It is possible to make these buildings very energy-efficient, but they present very different problems from those associated with timber-frame buildings.

Much of the initial development of highly energy-efficient masonry dwellings occurred in Sweden, Denmark and Switzerland. However, the same principles are now being applied in other countries with a masonry building tradition.

Valuable lessons have been learned. As a rule, it is considerably easier to reach good airtightness in masonry buildings than in site-built timber-frame ones. Conversely, to avoid thermal bridges needs much greater care in load-bearing masonry structures than in wooden-frame ones.

With care, very similar levels of insulation may be reached in masonry buildings and in timber-frame buildings. The comparison is seen most vividly in Denmark and Sweden, where designers routinely achieve U-values of less than 0.2 W/m^2K, in both heavyweight and lightweight building structures.

Under changing conditions, two parameters affect the behaviour of superinsulated heavyweight buildings. As well as their thermal resistance, discussed in the last paragraph, one must consider their thermal capacity.

The dynamic thermal behaviour of lightweight superinsulated buildings is stable, and fairly predictable. In response to a sudden heat input, or the onset of a spell of cold weather, they heat up and cool down at a noticeable rate. However, high mass, superinsulated buildings have an exceptional level of thermal inertia, and they behave in a way which is outside most peoples' everyday experience. This has potential benefits, but also has a few disadvantages. Both are discussed.

With the aid of examples from Scandinavia, mainland Europe, north America and the UK, this paper presents experience to date with the improved insulation of masonry buildings and attempts to reduce the level of air infiltration. Some noteworthy case studies are described.

INTRODUCTION

In the UK, Ireland, Denmark and mainland Europe, most buildings are constructed of brick, stone, *in situ* concrete, concrete blocks, precast concrete and other heavy materials. The timber-frame construction used in North America and most of Scandinavia is less common. This situation may well continue; the UK has just 8% forest cover, and it imports over 80% of its timber.

To achieve the expected performance, energy-efficient buildings need good insulation, with no major cold bridges, well-designed glazing and external doors, good air sealing and low ventilation heat loss. As a rule, it is a greater design challenge to avoid cold bridging in masonry buildings, but air sealing presents fewer problems. This paper presents recent experience with both.

Historically, with few exceptions, masonry buildings have been far less well-insulated than timber ones. Even within a single country, like Sweden, there was a timelag of some decades between the widespread adoption of thermal insulation in timber and in masonry buildings. Reasons are briefly discussed.

U-values of below 0.2 W/m^2K in the external walls and ground floor, and below 0.15 W/m^2K in the roof, are required by law in Sweden, under its 1989 building code. Masonry buildings; e.g., most blocks of flats, have to meet the same standards. Although the building codes of Switzerland, Germany and the Netherlands are less strict, several thousand equally energy-efficient masonry buildings have been built there [2].

The most energy-efficient dwellings, numbering perhaps 50, have gone even further. They have achieved U-values of little more than 0.15 W/m^2K. Along with stringent reductions in air leakage and ventilation losses, and improved glazings, this has proved to be sufficient in temperate climates almost to eliminate space heating energy.

AIR SEALING

Buildings which employ 'heavy, wet' construction can achieve a good level of air sealing. Provided that a few basic rules are followed, it is a fairly robust method, in this respect.

These basic rules include the need for wet plaster instead of plasterboard, the importance of fully-filled mortar joints in masonry walls, and the need to seal precast concrete components, either with *in situ* concrete or with sealant, at joints. In addition, where these elements of the building meet others, one must provide a positive sealing detail, and all services penetrations must be sealed.

The first evidence that air sealing of masonry buildings was relatively easy came from Sweden, in the 1970s. At the time, the building code was being tightened to conserve energy and airtightness testing was about to be introduced. Table 1 shows some results of tests carried out then on buildings with a structure of concrete, brick or timber, or a mixture of constructions; e.g., concrete walls and timber roof.

There is a consistent tendency for the totally concrete structures to leak less than the timber ones. Without special efforts, their leakage was less than 3 ac/h at 50 Pa, which the Swedish building code specified for detached houses from 1977 onwards, and often approached the 1 ac/h at 50 Pa, which became a requirement in 1978 for three-storey flats and taller buildings. At the same time, Swiss experience was publicised [4]. This came to exactly the same conclusion.

Very low air infiltration was reported from projects in Denmark, dating back to the 1970s and early 1980s [5-7]. It was of the order of 0.02-0.03 ac/h under normal winter temperatures and windspeeds.

Air leakage as low as 0.2 ac/h at 50 Pa has been achieved more recently on some state-of-the-art energy-efficient houses in Switzerland and Germany [8-9]. This may correspond to infiltration of some 0.01 ac/h.

Such figures seem to be lower than any result reported from timber-frame buildings in Sweden, where few houses leaked at a rate of less than 0.6 ac/h at 50 Pa [10]. It seems at least as tight as the best-sealed timber-frame houses reported from Canada.

Moreover, these European houses had timber roofs. The clear message is that buildings with concrete roofs would leak even less.

In masonry construction, the airtight layer is usually wet plaster or *in situ* concrete. Standard workmanship on this layer is usually sufficient to give an acceptable result, as long as some details are done differently. The need for greatest care arises at window and door openings, and services penetrations. Ways have been developed to give an acceptable level of sealing here, almost always in accordance with Danish experience.

Most of the recent energy-efficient UK projects have masonry walls and a timber pitched roof [11-12]. The external walls have been plastered, to make them acceptably airtight. However, the roofs, being of timber construction, need a vapour barrier. This polyethylene sheet has been trapped below a strip of reinforcing mesh, and the plaster layer overlaps it.

To date, in terms of air leakage, vapour barriers have probably given more problems than any other part of the building. The UK building trade is inexperienced in the use of vapour barriers, but well-practised in their misuse. This is largely because of ignorance and widespread misinformation. For example, it is still widely believed that water vapour diffusion is responsible for most of the moisture transported through building structures, although it is well-known in building research circles that most occurrences of interstitial condensation are attributable to the physical movement of warm, moist air.

In addition, UK workmanship is definitely of a lower standard than continental European countries. As a result, more robust details have to be produced. For example, *in situ* concrete floors and poured concrete walls are likely to be tighter than precast floors or masonry walls. Otherwise, a higher rate of air leakage has to be accepted, for a masonry building, than would be expected on the European mainland.

Buildings of timber-frame construction undoubtedly present greater problems than masonry buildings. However, they can be radically improved. One UK example of energy-efficient timber-frame construction was the 1985-86 Two Mile Ash houses. These had leakage of 1.5 ac/h at 50 Pa [13]. This level was considered exceptionally low for the UK; it may not have been equalled since in timber-frame. The same care has to be applied to the timber roofs of otherwise heavyweight buildings.

THERMAL INSULATION

For years, masonry buildings right across Europe, even in the colder climates of the east, had no thermal insulation. At the same time, timber-frame buildings in adjacent countries were being built with some insulation. The Danish building codes of the 1960s required insulation in timber frame buildings, but not in masonry ones.

The reasons are unclear. Historically, it was noted that on going across Europe from the maritime west to the severe winters of the east, masonry buildings simply had thicker brick walls. On reaching the boundary of Europe and the former USSR, where the coldest month is below -5°C, the thickness reached as much as 700 mm.

In heat loss terms, this was totally ineffective. 100 mm of mineral fibre has more thermal resistance than a medieval stone wall 3 m thick. It took a long time for this to be translated into actual building practice.

By the 1970s, several regions, notably Scandinavia and Switzerland, had learned that masonry buildings definitely needed insulation. Their regulations of this time generally specified 80-100 mm insulation.

Most other countries used no insulation in masonry walls until the late 1970s or even the early 1980s. By then, such countries; e.g., Greece, Turkey, the UK, the Netherlands and Ireland, started to require some insulation. Meanwhile, Denmark, which had used 50 mm to 100 mm insulation since the early 1960s, began to use 150 mm or even 200 mm in 'normal' buildings.

In all these countries, the 'low-energy' masonry buildings constructed after the 1973 oil crisis all had 2-3 times as much thermal insulation as 'normal', whatever that was. As early as 1977, low-energy buildings in Denmark had walls with up to 300 mm of insulation [14]. The connection between severity of climate and heat loss remained weak.

DYNAMIC THERMAL BEHAVIOUR

Under changing conditions, a superinsulated heavyweight building behaves very differently from a lightweight building of the same heat loss. Their static behaviour is the same, and this is the familiar quantity, but their dynamic behaviour is very different.

A lightweight structure responds faster to a change in internal temperature, or a change in external conditions, than a heavyweight one. This may be a reason why, in the past, far poorer insulation was tolerated in masonry buildings than in timber buildings.

Adding either thermal resistance or thermal capacity lengthens the building's time constant, Insulation was evidently used to alter the behaviour of lightweight buildings.

Although they lost heat equally rapidly, medieval stone buildings behaved in a different way from timber-frame buildings. Once their mass was heated to comfort temperatures, which might take a very long time, they stayed warm for a long time, despite being uninsulated. If the heat input was cut off, a timber building cooled very rapidly.

The behaviour of superinsulated timber buildings is similar to that of minimally-insulated masonry buildings, of the type generally built in Europe today. The heat loss is reduced five- or 10-fold relative to past practice, and a cooling time constant of 50-75 hours is typical. Their higher thermal resistance offsets their lower thermal capacity.

However, the behaviour of superinsulated masonry buildings transcends modern experience. They are characterised by a cooling time constant of hundreds or thousands of hours. 500 hours is typical of an above-ground masonry or concrete structure; 1,000 hours is possible. See Table 2. An earth-sheltered structure responds even more slowly, because so much of its envelope is coupled to the earth, not to the outside air.

Their thermal response is more sluggish than that of medieval European churches. Changes in internal temperature, which may be caused by either an internal free heat input, the onset of sunny weather, or a sudden change in external temperature, are dampened and delayed. Short of opening the windows or doors, significant shifts take weeks or months to be felt.

In the most extreme case, the temperature may change by less than 1 K between the beginning of a month and the end. The internal temperature profile shows little daily variation; over a series of sunny February days, with over 20% of the floor area in south-facing glazing, the air within the heavy masonry building only heats up by 2.5 K, falling back slowly later. A low-mass building of the same heat loss and same glazed area overheats to the point of discomfort, rising from an air temperature of 20 to 27°C within hours; Figure 1. The dwelling construction details are taken from a companion paper to this conference [15].

For this reason, Swiss architects found that the U.S. work on passive solar houses was actually far more readily-applied to the buildings constructed in central Europe. These were so heavyweight that they could absorb the solar gains without overheating [16].

This thermal sluggishness could be a problem, in buildings which need a large energy input for space heating. It almost rules out intermittent heating, and the attendant energy savings. However, where the mean solar and internal gains, combined, are enough to heat the building, it may be an advantage, as the building is always comfortable.

Once one has reached ultra-low space heating energy, heavy buildings may be more comfortable than lightweight ones. Sudden heat gains, from the sun or elsewhere, give rise to smaller temperature fluctuations. In a temperate climate, if one wishes to eliminate the need for space heating energy by 'passive' means, the use of high mass construction seems to be important. This conclusion may be different in cold climates.

The corollary is that, if prolonged over- or under-heating has occurred as a result of control failure, it is hard to alter the internal temperature rapidly. This may need cultural shifts to be accepted, or people may welcome operative temperatures which change extremely slowly, and, unlike normal buildings, are virtually always within the ASHRAE comfort zone.

HEAVYWEIGHT BUILDING ELEMENTS

ROOFS

Most roofs can be classed as pitched timber structures or flat concrete ones. The former present basically the same problems, and the same opportunities for insulation, as North American roofs.

The latter are increasingly being treated as inverted roofs. The insulation is outside the waterproofing/vapour barrier. In a concrete roof, there is usually nowhere within the structure where insulation could be sited.

Turf-covered roofs are a new departure in the UK. From an insulation and waterproofing viewpoint, the bulk of them have been treated as inverted concrete roofs, and extruded polystyrene has been used.

However, there are still very few earth-sheltered buildings. The protective effect of the turf may be found to lengthen the membrane lifespan, to virtually the same lifespan as the rest of the building structure. If so, more 'warm' flat roofs may be used; they can use cheaper, and perhaps less environmentally-harmful, insulation materials.

WALLS

Today, heavyweight building practice varies widely between countries. This reflects different traditions, and also reflects building practice in those regions before the advent of thermal insulation.

There is as much diversity as with timber-frame walls. However, walls can be broadly divided into two classes, according to the position of the insulation.

Cavity masonry walls dominate northern Europe; e.g., the UK, Ireland, the Netherlands, Denmark and north Germany. Here, the insulation goes in the cavity. Solid masonry walls dominate central and southern Europe; e.g., Germany and Switzerland. Here, the insulation usually goes on the outside. In Sweden and Norway, where masonry walls are used, in flats or offices, they are usually cavity walls.

Internal insulation is not considered further. It is ineffective in well-insulated masonry buildings, as it leads to extensive thermal bridging. It also gives the building a dynamic behaviour more like that of lightweight buildings.

The cavity wall did not develop because it was a good place to put the insulation. It developed because, in cold, wet climates, it was a good way to keep the water out of the building. Following a spate of cavity failures in the UK in the 1970s, this has given rise to claims that full cavity fill raises the risk of water penetration.

For several reasons, a clear cavity no longer seems so appropriate. The energy-efficient buildings now constructed in the Netherlands, Germany, and all the new buildings in Denmark, have 125 mm or more insulation in the cavity, not 50 mm. It is generally agreed that wide cavities are considerably less prone to problems. The most common defect, namely mortar lumps which totally span the cavity, is actually quite difficult to replicate when the gap to be bridged is 150 mm.

Second, it is worth considering experience from Denmark, the country with the most experience of insulating brick cavity walls. Its west coast suffers from horizontal driving rain, but research was done 25 years ago to determine whether cavities fully-filled with mineral fibre caused water penetration. At the time, 80 to 100 mm cavities were prevalent.

The answer was that with reasonable workmanship, insulation did not cause water problems, and with poor workmanship, even empty cavities led to water penetration. The need for satisfactory workmanship was paramount. If this condition was satisfied, fully-filled cavities were the best strategy to save energy at moderate cost.

There are more doubts over the water resistance of walls filled with the other insulating materials, such as plastic foams. However, some cavity walls are being built in the Netherlands and sheltered parts of the UK which are fully-filled with expanded or extruded polystyrene, or with polyurethane foam slabs.

In situ polyurethane foam has extraordinary abilities to seal cracks and gaps, but it has not been widely-applied this way yet. This is apparently because of a 'catch-22' situation; it is too expensive as a one-off job, and it will not be used in bulk until it is cheaper.

Virtually the only advantage of using plastic foams seems to be their lower thermal conductivity, and the thinner wall which results for a given thermal resistance. It appears that it is usually cheaper to design a thicker wall and insulate it with a cheaper material.

There are limits to the width of insulation in masonry walls. The first is the structural behaviour of wide cavity walls. Danish plastic wall ties, developed for use in cavity walls, stop at a length corresponding to a cavity thickness of 250 mm. Beyond this, there is much doubt over whether a cavity wall functions as a single unit. If it does not, one must use a self-supporting outer leaf, thickened with piers.

In solid walls with external insulation, the main limit is the strength of the bond between the insulation and the masonry, and the bending forces exerted. Until about 1988, the usual limit to insulation thickness was around 180 mm. Now, systems for 350 mm insulation, either high-density mineral fibre or expanded polystyrene, are available from German companies.

'Normal' energy-efficient buildings in Denmark are still using only 200 mm wall insulation, and in the UK and Germany they are using around 150 mm. The ability to 'expand' to 250 mm in cavity walls and 350 mm in solid walls should suffice for the foreseeable future.

Table 3 indicates the wall thicknesses implied by high, and very high, levels of insulation (characteristic of so-called 'low energy' and 'zero-energy' houses in Germany and the UK. The U-values are respectively 0.2-0.25 and 0.1-0.12 (respectively, R-4 to -5 and R-8 to -10).

In the extreme case, to get the lower U-value, one ends up with a 600 mm (2 ft.) thick wall. To readers from 'timber-frame' countries, where 300 mm constitutes a very thick wall, these are massive structures. However, they conform closely to the vernacular architecture of Europe, pre-1850. This was dominated by thick masonry walls, 400-800 mm thick.

We have come full circle, back to the thick wall. The main change is that the centre of this new wall is filled with insulation, not masonry rubble, and its thermal resistance is 5 to 10, not 0.4-1 m^2K/W. With the same thermal insulation levels elsewhere in the building, it can be heated mainly by the occupants; the roaring fire so typical in the past, even in moderate climates, is not needed.

GROUND FLOORS

Ground floors can be divided into concrete slabs-on-ground, suspended concrete floors and basement foundations. Timber suspended floors are becoming rarer, and are not discussed.

Except perhaps in areas of deep, well-drained sandy soil, experience suggests that floors built on the ground need full insulation. In Denmark, it was found advisable for heated basements, and foundations in general, to be almost as well-insulated as the structure above the ground [17].

Cellars

Basements have been rare in the UK since the 19th century, but may return. On the shrinkable clay soils which prevail in south-east England, foundations must now be 1.5 m deep; the extra excavation needed to form a cellar is modest. In urban areas, basements make better use of scarce land, and are routinely used in non-domestic buildings. In earth-sheltered structures built into a south-facing slope, basement-style construction is used.

In Sweden, almost without exception, new dwellings have concrete slabs on ground, with a layer of high-density mineral fibre below the slab. Concrete basements, where used, may utilise external mineral fibre insulation and drainage only, without active waterproofing.

In Germany, cellars are a virtual requirement, but insulation is not, even where the cellar is within the thermal envelope. To date, the best example of proper insulation is the 16 Darmstadt ultra low-energy houses. The cellar ceiling was insulated and a course of lightweight concrete concrete blocks, with insulating mortar, was used in the external walls, to achieve continuity in the insulation layer at this point. See Figure 2.

In Switzerland, the most effective insulation system to date was applied to the ten Wadenswil zero-energy and ultra-low energy houses. Here, a heated cellar was specified. A reinforced concrete raft was used to spread the load, and the 3.5-storey concrete buildings were supported on a layer of 120 mm extruded polystyrene. This achieved total continuity with the 150 mm extruded polystyrene on the cellar walls, and the 180 mm extruded polystyrene on the above-ground walls. German and Swiss designers have also used cellular glass in this situation, albeit at substantially higher cost.

In the context of modern energy-efficient buildings, it is too early to comment on UK basement insulation. A few insulated basements have been specified for non-domestic buildings, generally with external insulation of extruded polystyrene or cellular glass.

In a recent building at the University of East Anglia, Norwich, England, the cellar retaining wall has been insulated externally with 100 mm extruded polystyrene, but the cavity wall continues down below ground as far as possible. At the transition point between masonry and reinforced concrete, lightweight concrete block is used, and the insulation layers overlap. This gives an entirely acceptable path length, at the overlap.

Suspended ground floors

With rising timber costs, and worsening ground conditions, suspended concrete ground floors have become common in the UK. Usually, in mass housing, rigid insulation is laid above a beam-and-block floor and chipboard is laid on top, in a floating floor arrangement.

This arrangement is not very durable, and being dry construction, has a risk of air leakage. To give a more robust construction, one can use proprietary, 50-150 mm thick polystyrene formwork as permanent shuttering, on a base of precast concrete beams. This gives an airtight, fairly well-insulated ground floor, albeit with an insulation layer of uneven thickness.

Some builders who want even more insulation than this have placed a sand-cement screed above the insulation, on top of a beam-and-block floor. Up to 150 mm expanded polystyrene has been used in this way.

Concrete slab-on-ground

Concrete slab-on-ground foundations are insulated either below or above the slab. A substantial level of insulation is being used in energy-efficient buildings, up to 100 mm extruded polystyrene or 200 mm of expanded polystyrene.

Whole floor insulation is being used. On one UK project with perimeter insulation only, the floor heat loss was surprisingly high [18]. In the context of low-energy buildings, the consequences seem far too high to risk omitting the insulation.

Most UK projects are using expanded or extruded polystyrene. Few clients seem able or willing to pay the extra cost of high-density mineral fibre or cellular glass.

Unless care is taken, there is a cold bridge at the foundations; the floor insulation fails to meet the wall insulation. Research in Denmark showed that the most effective way to reduce edge heat losses was to use lightweight concrete blocks in the inner leaf of a cavity wall, and to extend this construction 0.6 m below ground.

In Germany, the same detail has been used in solid walls; Figure 3. There are even ways to achieve continuity of the insulation, without even interrupting it by lightweight concrete block. To do this, one uses load-bearing insulation, such as cellular glass. This approach has been restricted by the high cost.

CASE STUDIES

It is too early to be definitive, but some super-insulated heavyweight buildings in the UK are giving excellent results. The air leakage is low, and so is the resulting energy costs for space heating.

In Scandinavia, the Netherlands, Germany and Switzerland, the evidence is conclusive. Such buildings perform as well as timber-frame ones of the same insulation level, and they are less difficult to build.

The first UK example is a masonry and concrete earth-sheltered structure built at Caer Llan, Monmouth, South Wales, in 1988. It is basically a well-insulated, passive solar, single-storey building, partly buried in a south-west-facing bank. It is insulated with 15-100 mm polyurethane foam, and the S.S.W-facing windows are argon-filled double glazing [19].

It cost some £330 per m^2, excluding the owner's management time in acting as general contractor. This was the same as a conventional new building.

Since completion, Caer Llan has used no fossil fuel for space heating and cooling. The air temperature has remained in the range 18-24°C. The only energy cost for space conditioning has been £110/year worth of electricity to operate the mechanical ventilation system, and even this could be reduced, if the design was replicated, by using larger ducts and more efficient fans.

The second example is a recent block of student residences at the University of East Anglia. They are built of dense concrete masonry, with insulated cavity walls, concrete upper floors and flat concrete roof. Preliminary results suggest that they may be as tight as typical new Swedish multi-family buildings. In Sweden, such buildings must have air leakage of < 3 m^3/h per m^2 external envelope area, at 50 Pa. For a four-storey block, this translates as < 1 ac/h at 50 Pa [20].

One existing heavyweight, superinsulated UK house has given a far superior standard of summer comfort to conventional buildings, even high-mass ones with no insulation [21]. This was the most unexpected result of the project, which was designed principally to reduce winter space heating costs.

At least one heavyweight Swiss office building provided operative temperatures which were always in the range 18-23°C, and never changed by more than 0.2 K per hour in summer, or 0.1 K/hour in winter. Although these temperatures could not be changed rapidly, they proved very acceptable to the occupants. The temperature next day, and the appropriate level of clothing, could be forecast by reference to the temperature history of the last week [22].

LOW EMBODIED ENERGY - DOES IT RULE OUT HEAVY BUILDINGS?

In the UK, the embodied energy used to construct buildings has attracted much attention and misunderstanding. While important, it is emphatically a second order effect, and it is bizarre to pay as much attention to this as to reducing the amount of energy consumed to heat and light the building. The latter is an order of magnitude greater.

One's first assumptions can be counterintuitive. In timber-importing countries, the more favourable forms of heavyweight construction do not necessarily take any more 'embodied' energy than a timber-frame building of the same insulation level [23]. The materials to avoid are generally clay bricks, and unnecessary use of reinforcing steel in concrete, in circumstances where a somewhat greater thickness of mass concrete would suffice.

A poster paper at this conference contains details of a project where this issue will be a design criterion. The embodied energy of the main elements of this building should be 30% lower than normal UK buildings, despite a more robust external wall construction, and a thermal resistance four times higher than normal [24].

Unless it obtains its energy supply entirely from renewable sources, even an ultra-low-energy building consumes more fossil fuel to operate over its life cycle than it takes to build. If total demolition is needed every 250 years, and more energy must then be reinvested in a new structure, the construction energy is about 20% as much as the operating energy. This assumes that 360 GJ is taken to build a 100 m^2 house, and 8 GJ/yr of fossil fuel is used to operate it. The answer may be to design and build structures to last many centuries, not decades.

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Table 3. Examples of highly-insulated (U = 0.2 to 0.25) and very highly-insulated (U = 0.1 to 0.14) external walls.

HIGHLY-INSULATED				
Construction (outwards)	13 mm dense plaster 100 mm dense concrete block 150 mm mineral fibre 150 mm stone	13 mm dense plaster 100 mm dense concrete block 150 mm mineral fibre 100 mm clay brick	13 mm dense plaster 200 mm dense concrete block 150 mm expanded polystyrene 20 mm external render on mesh	13 mm light plaster 100 mm lightweight concrete block (k = 0.2) 150 mm mineral fibre 100 mm lightweight concrete block 20 mm external render
U-value	0.22 W/m^2K	0.23 W/m^2K	0.21 W/m^2K	0.20 W/m^2K
Thickness	400 mm	350 mm	370 mm	370 mm
VERY HIGHLY-INSULATED				
Construction (outwards)	13 mm dense plaster 200 mm dense *in situ* concrete 250 mm mineral fibre 150 mm stone	13 mm dense plaster 100 mm dense concrete block 250 mm mineral fibre 100 mm clay bricks	13 mm dense plaster 225 mm dense concrete block 300 mm expanded polystyrene 20 mm external render	13 mm lightweight plaster 100 mm lightweight conc. block 250 mm mineral fibre 100 mm lightweight conc. block 20 mm external render
U-value	0.13 W/m^2K	0.14 W/m^2K	0.11 W/m^2K	0.13 W/m^2K
Thickness	600 mm	450 mm	550 mm	470 mm

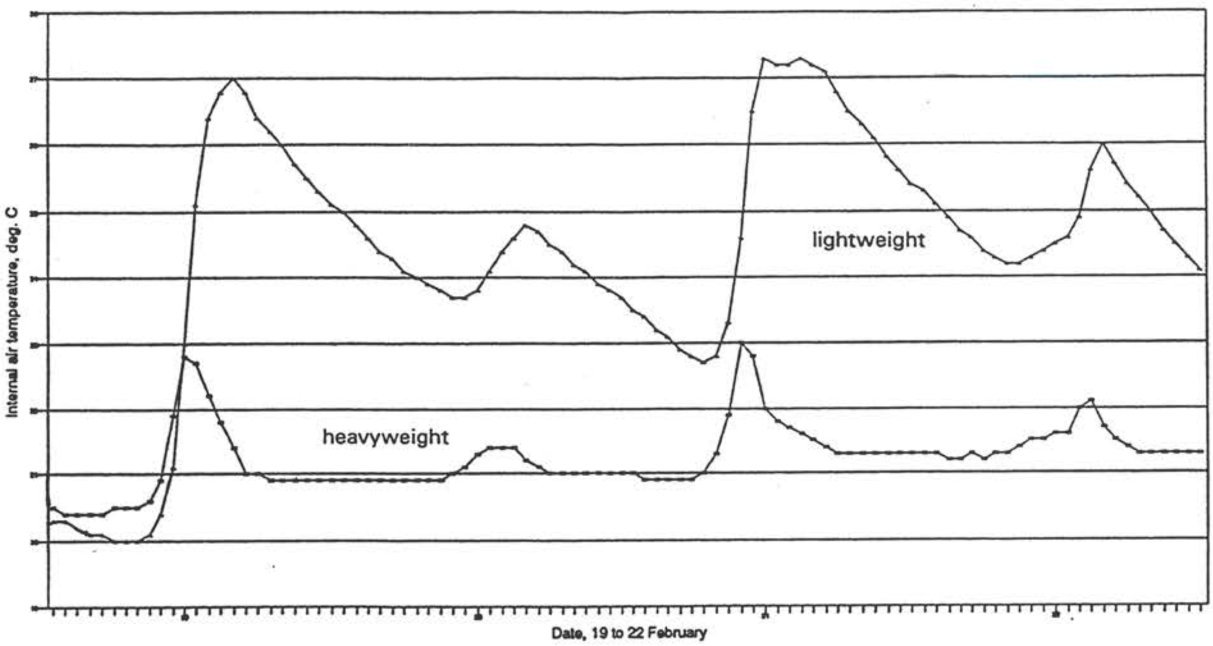


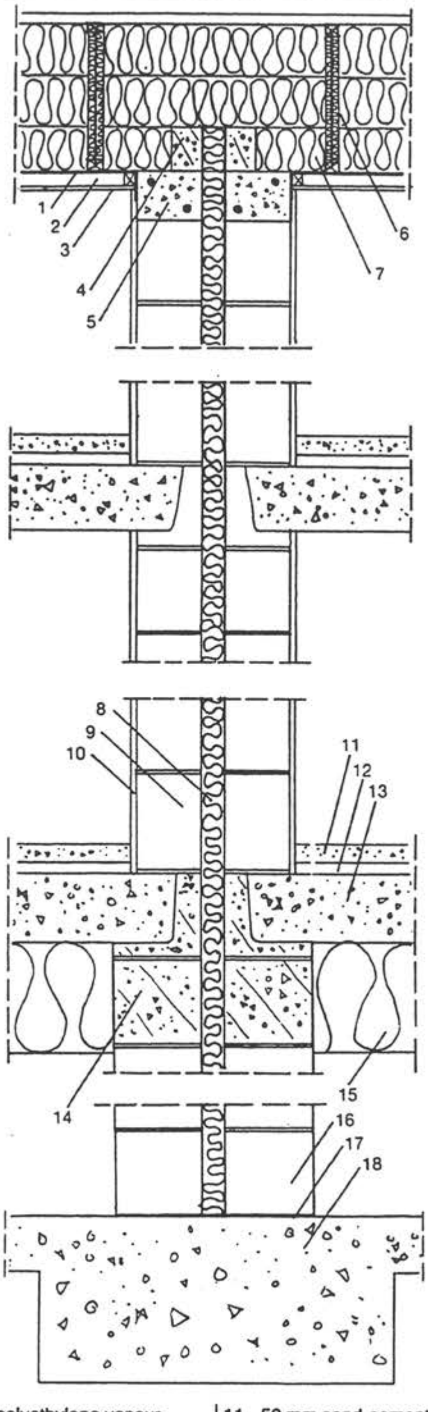
Figure 1. Simulated hourly temperature variation, very highly-insulated dwellings, over four days of sunny late February weather.

Table 1. Air leakage of Swedish detached houses, pre SBN-80, by construction type [3].

House type	*External walls*	*Upper floors*	*Roof*	*Leakage* (ac/h at 50 Pa)
2-storey	Concrete	Concrete	Concrete	1.38
1.5-storey	Concrete	Concrete	Timber	2.44
1-storey with basement	Concrete	Concrete	Concrete	1.54
1-storey	Concrete	Concrete	Concrete	1.75
1-storey	Concrete	Concrete	Concrete	1.59
1-storey with basement	Concrete	Concrete	Timber	3.25
1.5-storey with basement	Concrete	Timber	Timber	2.70
Split level	Concrete	Concrete	Concrete	1.28
1-storey with basement	Concrete	Concrete	Timber	1.72

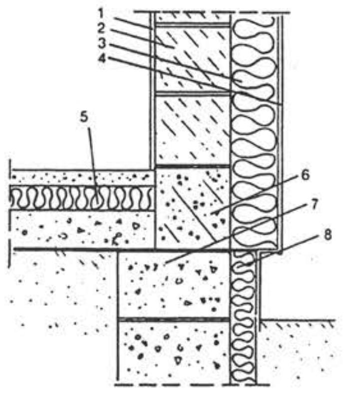
Table 2. Typical cooling time constants of a new dwelling, by thermal integrity and construction type [15].

CONSTRUCTION TYPE	*TYPICAL COOLING TIME CONSTANT* (hours)
UK Building Code (heat loss 260 W/K for 100m²)	
Timber-frame	10
Masonry	100
Heavy masonry	200
Superinsulated (heat loss 55 W/K for 100 m²)	
Timber-frame	50
Masonry	500
Heavy masonry	1,000



1 - polyethylene vapour barrier
2 - space for electrical wiring
3 - plasterboard
4 - lightweight concrete blocks
5 - reinforced concrete beam
6 - mineral fibre-filled I-beam
7 - 400 mm mineral fibre, 120+140+140 mm
8 - 70 mm mineral fibre
9 - 175 mm calcium silicate blocks
10 - 15 mm plaster
11 - 50 mm sand-cement screed
12 - acoustic insulation
13 - 180 mm reinforced concrete floor
14 - two courses of 240 mm lightweight concrete block
15 - 300 mm expanded polystyrene
16 - 240 mm calcium silicate blocks
17 - polyethylene film
18 - concrete footings

Figure 2. Cross-section through the Darmstadt ultra-low-energy houses [2].



1 - 15 mm plaster
2 - 240 mm fired clay blocks
3 - 150 mm expanded polystyrene
4 - external render
5 - 80 mm polyurethane foam
6 - 240 mm lightweight concrete block
7 - 365 mm dense concrete blocks
8 - 80 mm extruded polystyrene

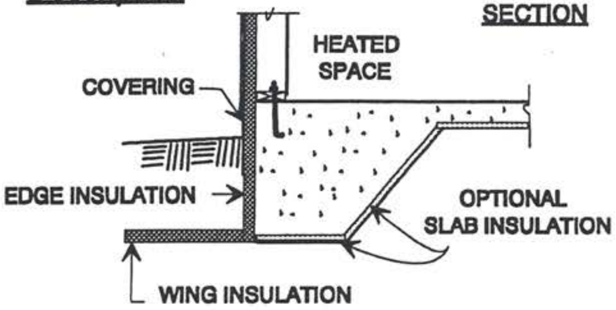
Figure 3. Typical construction detail used to reduce thermal bridging at foundation, in externally-insulated masonry walls [2].

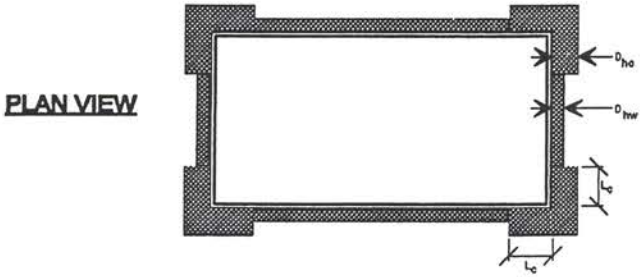
Frost Protected Shallow Foundations

NAHB Research Center

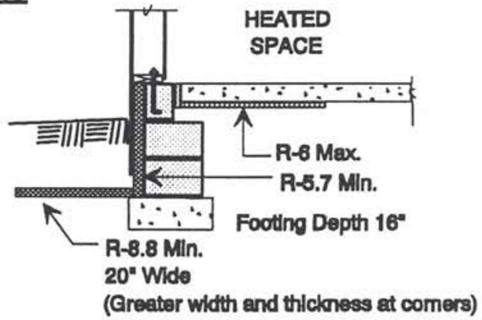
Dan Cautley

Description



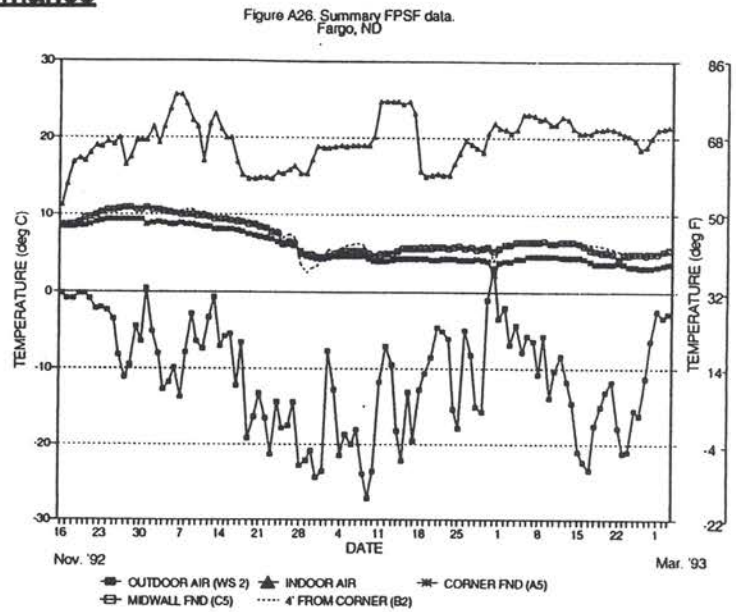


Design Example



Design based on Freezing Index of 3,500 F Day (typical of U.S. - Canadian border)

Performance



Benefits

Cost Savings	$1,500 (+/-) 15 - 20% of foundation cost 2 - 4% of home cost
Time Savings	Up to 3 days
Energy Savings	Meets or exceeds MEC requirements

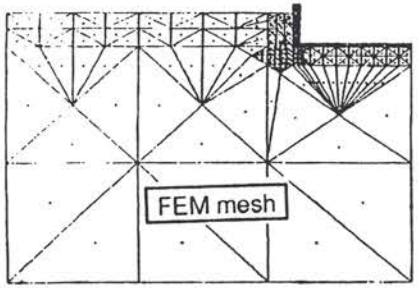
Reference

Frost-Protected Shallow Foundations in Residential Construction
U.S. Dept of Housing and Urban Development (HUD), 1993

Calculating Basement Heat Losses

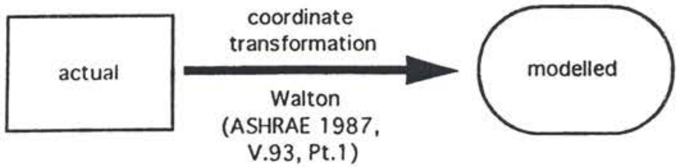
Ian Morrison (Buildings Group, CANMET) and Gintas Mitalas (Consultant)

step 1: model the basement's cross-section with a 2D FEM(ii).

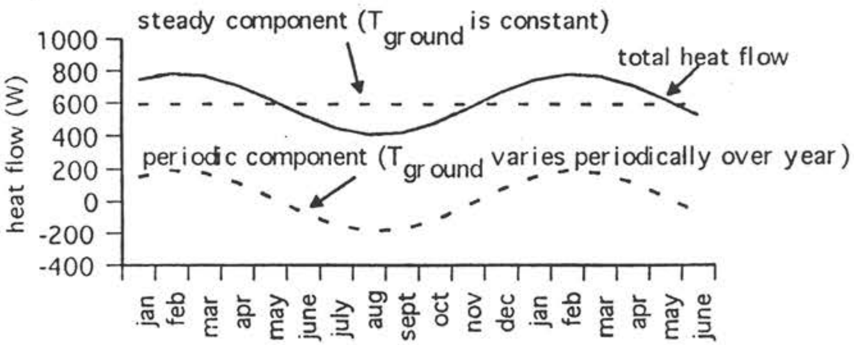


Goals:
- improve the Mitalas method
- develop a user-friendly interface
- make the method available in DOS
- enhance HOT2000(i)

step 2: model the corners with a modified 2D FEM(ii).

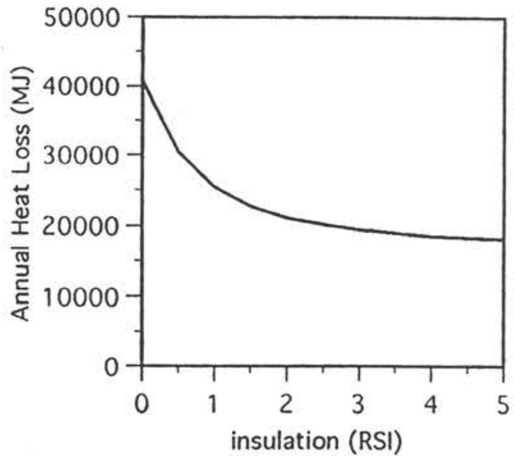


step 3: superimpose the steady and periodic components.

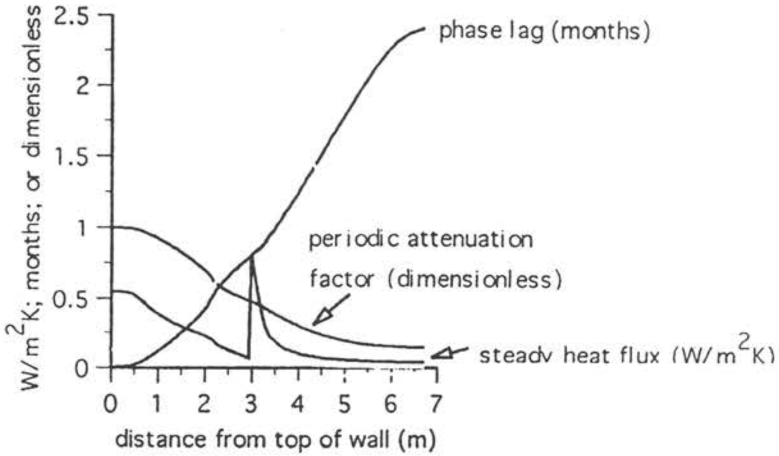


(i) HOT2000 is a monthly-bin simulation program for houses
(ii) two-dimensional finite-element method

example result: full-height interior insulation



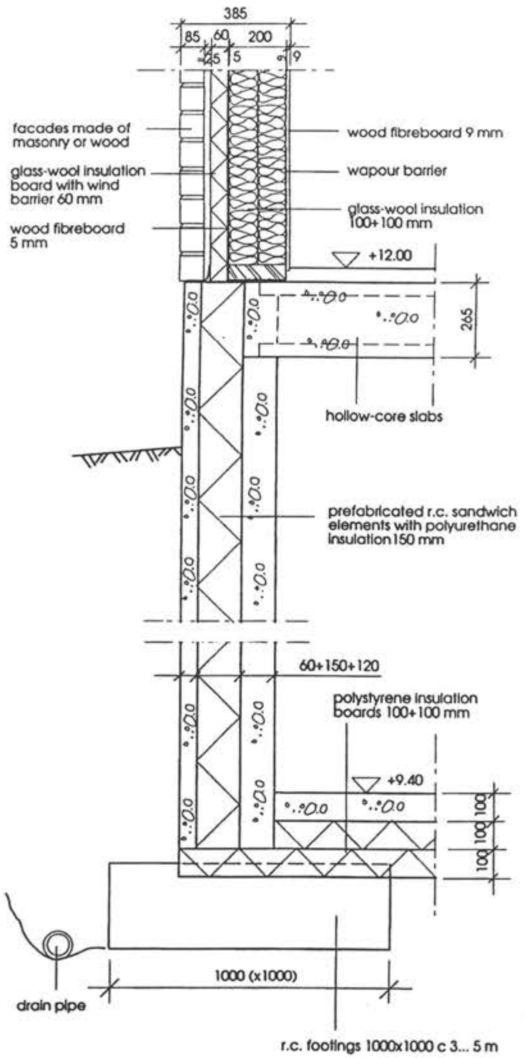
example result: interior insulation to 0.6m below grade



Envelope Structures for Two Low-energy Single-family Houses in Finland 1992-93

Mr. Pekka Leppänen, Technical Research Centre of Finland, Division of Building Technology
and Community Development, Laboratory of Structural Engineering

The Renlund House



Why?

Finland uses 6 Mtoe of energy per capita annually, 22% of this amount just for heating buildings. Something needs to be done to decrease this amount.

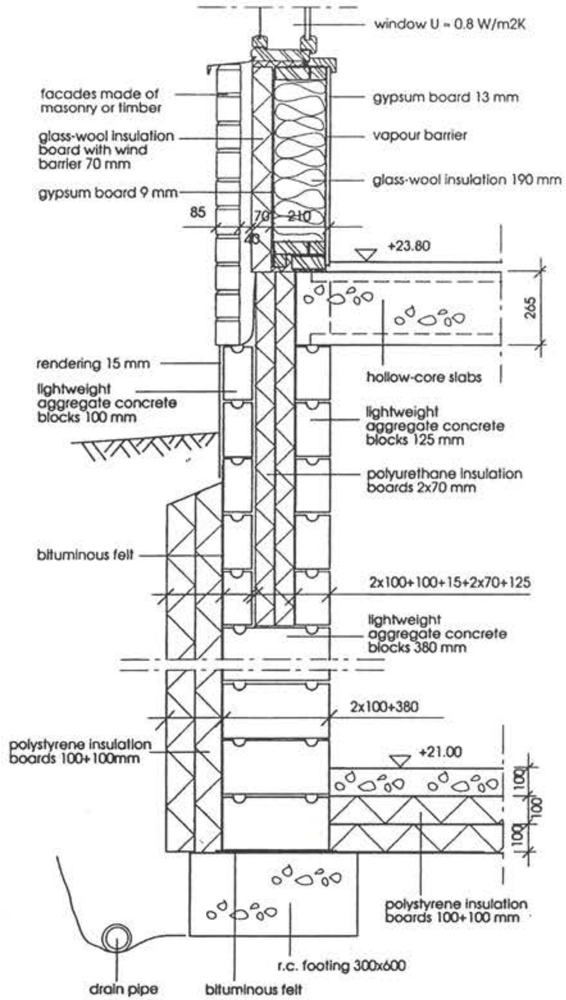
Tasks of this pilot project:

To develop and build single-family houses for two ordinary Finnish families, the aims being:
- improved indoor air quality
- decreasing heating energy down to 40 kWh/m2 a
- no sophisticated new products: All building components must be generally available in shops

Next phase:

In the next pilot houses some companies will develope their products into ready-for-use industrial products.
These products will allow everyone to build a low-energy house without special consultancy.

The Kanerva House



DYNAMIC INSULATION ENVELOPE
ENERGY SAVINGS AND THERMAL COMFORT

S.Croce, B.Daniotti, E.De Angelis
DISET – Politecnico di Milano – P.za Leonardo da Vinci, 32 - Milano (Italy)

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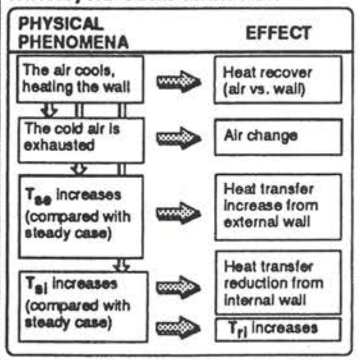
INTRODUCTION

A full scale test (granted by CNR) has been developed to check artificially ventilated cavity windows thermal behaviour when used to exhaust air. The test evaluated thermal comfort and energy saving performances and their improvement.
It is possible to understand global loss reduction if heat and mass balance is evaluated at the internal boundary of the system.
The designed experimental facility simulate outdoor and indoor winter environments; heat flux through windows and superficial temperature mapping are evaluated in steady state conditions, varying cavity air flow, for two window types.

BEHAVIOUR ANALYSIS

winter, no solar radiation



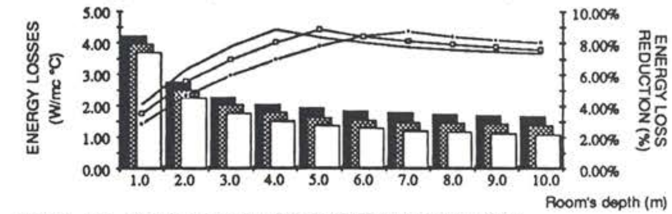
convective comfort control
radiative comfort control
energy transfer control
internal ventilation control

NOTES

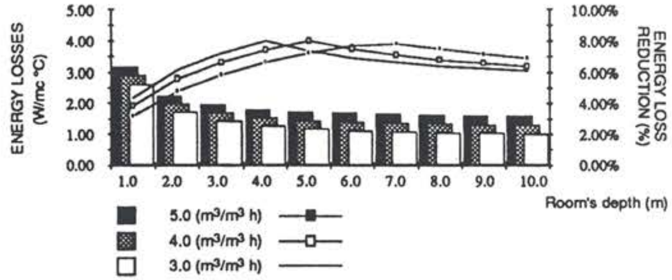
Gap air flow increases surface temperatures, heat flow from indoor air to window decreases, while flowing air looses a part of its enthalpic content.
Air flow seems to better thermal performances of not exhausting configuration: it reduces winter heat charge, and improves radiative indoor comfort conditions.

ENERGY SAVING ASSESSMENT

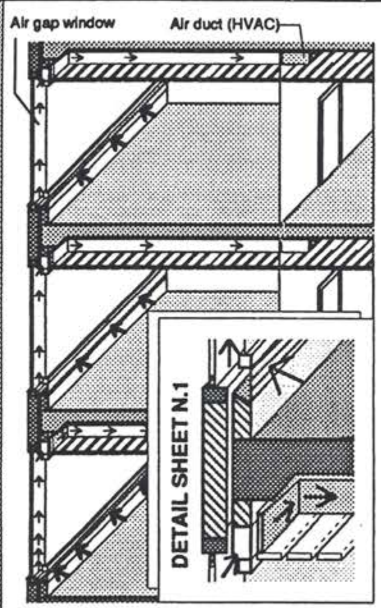
TWO SINGLE GLASS PANES (K = 2,9 W/mq°C)
Total energy losses per unit volume versus its depth



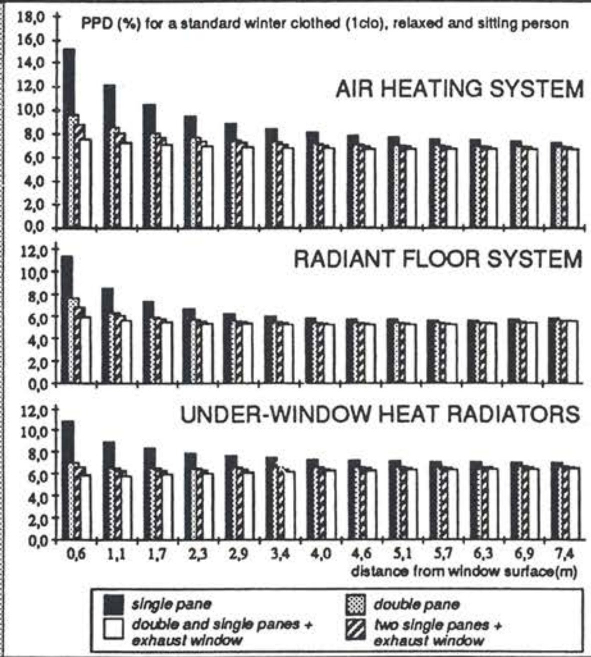
SINGLE + DOUBLE GLASS PANE (1.8 W/mq°C)
Total energy losses per unit volume versus its depth



THE SYSTEM

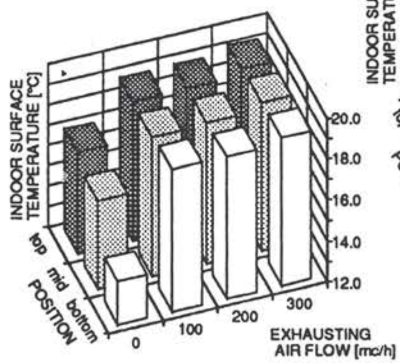


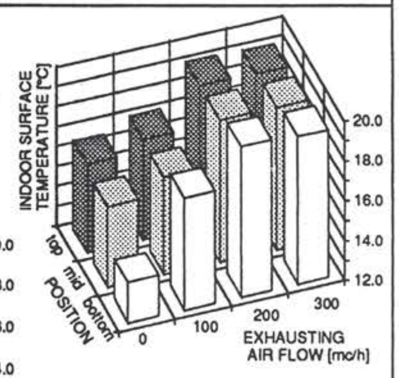
THERMAL COMFORT ASSESSMENT



LABORATORY RESULTS

SINGLE + DOUBLE PANE EXHAUSTING WINDOW





TWO SINGLE PANES EXHAUSTING WINDOW