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Norwegian Building Research Institute

Sverre Fossdal

Windows in existing buildings – maintenance, upgrading or replacement?

Windows in existing buildings in a sustainable perspective

192 Project report 1996

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(Riksantikvaren)
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Preface

This paper was written for the Directorate for Cultural Heritage, as a contribution to a discussion about how the knowledge and experience found in cultural reminiscences connected to buildings can be seen a sustainable perspective.

This paper is published in connection with the IV European Conference of Ministers responsible for the Cultural Heritage. THE CULTURAL HERITAGE: AN ECONOMIC AND SOCIAL CHALLENGE. Finland 30 and 31 May 1996.

Mr. Knut Ivar Edvardsen, Norwegian Building Research Institute, Mr. Sjur Helseth and Mr. Dag Myklebust, Directorate of Cultural Heritage have contributed to this paper as a reference group.

Oslo, May 1996

Sverre Fossdal

Content

Summary

The main task of the Directorate of Cultural Heritage is to preserve and take care of our older buildings as a heritage for future generations. Old windows in existing buildings represent an important part of this heritage.

The durability of windows depends on material used, construction, maintenance and how exposed the windows are to weather. Norwegian windows must stand up to the extremes of high Atlantic winds, driving rain, snow, ice and inland temperatures which can vary from +35 °C in summer to -50 °C in winter. There are many examples showing that the lifetime of old windows, where old craftsmen's knowledge has been applied, may exceed 250 years, while new windows, in practice, will have a shorter lifetime. The most common reasons for people to change their windows is to achieve better thermal insulation, easier service and maintenance or reduction of traffic noise and not the necessity caused by deterioration. The replacement of old windows may have disastrous effects on the appearance of a building even if the new windows are near copies of the existing ones.

The Conference in Rio de Janeiro in Brazil in 1992 stated that the main reason for an increased depreciation of the global environment was a non sustainable production- and consumption pattern especially in the industrialised countries.

To get a better understanding of how products influence the environment throughout their lifetimes, a life cycle assessment is carried out.

A life cycle assessment of new coupled windows with double glazing, new windows with energy saving glass and old windows supplied with an inner frame with single and double glazing, have been carried out with reference to an existing block of flats from 1887. It is assumed that the building is heated with electricity and that the electricity is produced from hydropower with no emissions to the air. The chosen functional unit is per window and 90 years.

The results show the smallest environmental impact if the old windows are supplied with an inner frame with single glass followed by old windows supplied with an inner frame with double glazing. This is with respect to all the environmental categories (global warming potential, acidification, photo-oxidant formation, eutrophication and consumption of fossil fuel) over a period of 90 years.

The total energy consumption for a period of 90 years, however, is higher for the old windows supplied with both inner frame with single and double glazing than with new windows with energy glass. For the chosen building the calculations show approx. 5 % higher total energy consumption in the user phase for the building with old windows with inner frames with single glazing but only 1 % higher for both old windows with inner frame with double glazing and coupled windows with double glazing compared to new windows with energy glass. The calculations have been carried out for the climatic conditions in Oslo.

1 Introduction

One of the tasks of the Directorate of Cultural Heritage is to preserve and take care of our older buildings as a heritage for future generations. In many ways old windows in existing buildings represent an important part of this heritage.
Many of the buildings which need to be refurbished were built in a period when aesthetic creation was given high priority. Symmetry, conceivable regularity and size and shape of windows were important visual elements in the facade.
Today, functional requirements and vague wishes of more modern windows often lead to replacement of existing windows. In general the replacements differ from the original windows with regard to frame and sash profiling and dimensions, and very often also in types of opening mechanisms. New requirements and details related to air and rain tightness of the window to wall joint require windows which are a little smaller than the old ones to fit the opening in the wall. These factors may, separately or in combination, be conductive to ruining the original appearance of the building.
In many ways the development of windows through history follows the development of glass production and the availability and price of window glass. It was mainly in churches, castles and later on houses belonging to the upper and middle classes where windows first were used. Large windows and many panes became an indication of high social and economic status.
The oldest window - where glass is used - is the lead glass window. It had crossbars of lead and a wooden frame which was shored with iron bars. These windows could normally not be opened. These types of windows were common in Norwegian towns from approximately 1560 to the middle of the 17th century and in the countryside until year 1800. In the beginning of the 17th century crossbars of wood was used and from the middle of that century the small paned baroque windows controlled the market in the cities. From the 15th century till today the windows has changed from many small panes to a large single pane in each frame. The development from single pane windows to windows with double or triple glazing has taken place in our century. Figure 1 shows different types of windows used in Norway from approximately 1560 to 1960.

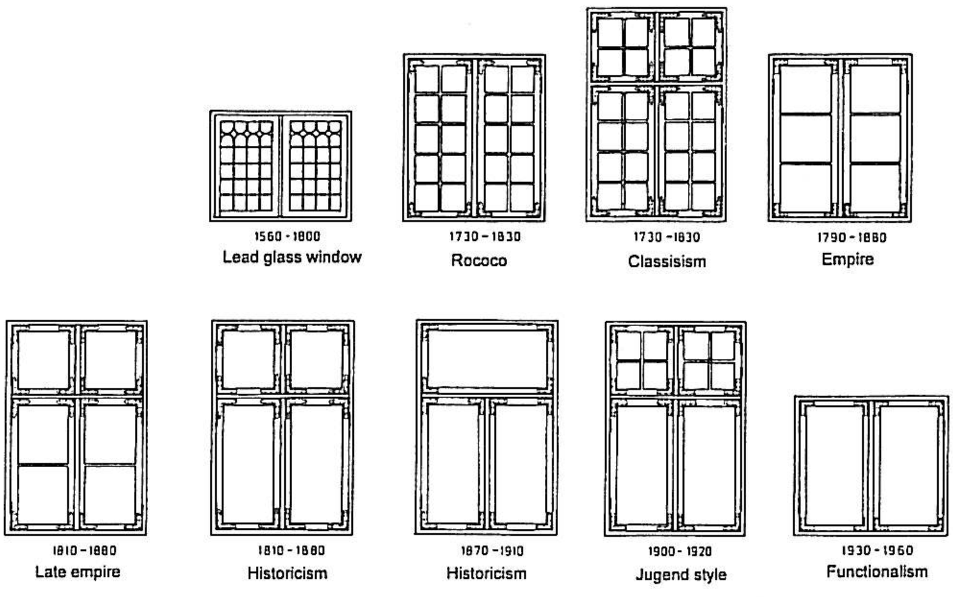


Fig 1
Common Norwegian windows

Production of glass started in Norway in the 17th century. Until then glass was imported. From the start production of glass was done by glassblowing. When the glass bubble (blister) was opened and rotated the centrifugal force entailed the glass to form a circular disc. This type of glass (called crown glass) which had thicker part in the middle could reach a diameter of approx. 1.25 m. At the end of the 17th century a method was introduced were the glass mass was formed as a bottle, the ends removed and the remaining cylinder opened and planed (taffel glass). This production method gave less waste and more even pane thickness.
The industrial production of window glass in Norway started in the beginning of the 19th century. First as a rolled glass production and later in a float glass production process. From the end of the 1980's all window glass is imported.

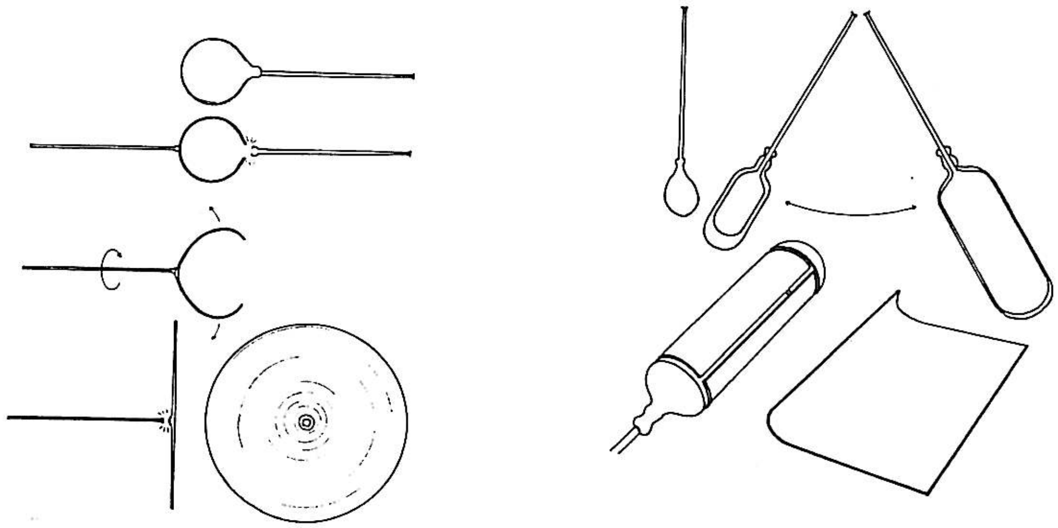


Figure 2
Production of crown glass and taffel glass.

Some 100 years ago production of windows was carried out by trained craftsmen, who not only selected the timber and sorted the material to produce the different parts of the window taking into account the density of the wood and the orientation of the growth rings, but who also to some extent decided which trees were best suited for a certain type of production. Spruce and pine were the most used materials, but pine was preferred in window production. It was required that timber for window production should be narrow-ringed, straight and have a minimum of knots. It was recommended that the trees were barked a few years prior to felling to fill the trunk with resin and tar and become more resistant against decay.
The durability of windows depend of many parameters; material quality (density, orientation of the timber growth rings, natural impregnation), frame and sash profiles, joining method, maintenance and weather exposure. Many examples show that the life time of old windows produced by skilled joiners may exceed 200 years, while in practice new windows will have a shorter lifetime. In modern manufacturing the tendency is to increase the lifetime of windows by using other materials to protect the timber, e.g. chemical treatment and aluminium flashing, rather than depending on the natural properties embodied in the material. There is a general quality control with regard to cracks and knots, but the timber is normally used without considering properties like heartwood, density and orientation of annual rings.

The main function of a window is to let daylight into the building and allow people to view the surroundings from the inside. At the same time the window is an important part of the climate shell protecting the interior against wind and precipitation. In the past the specific heat loss through windows was much higher than for the rest of the building, but development and improvement of windows in later years have narrowed this difference considerably.
The energy loss through closed windows is a result of their U-values and air tightness. For older windows the latter may probably be the most significant. There is also a heat gain through the windows on sunny days.

The production has developed from being a craft where the knowledge of the timber and the skill of the craftsmen was of crucial importance for the durability, to a 100 % industrial product where costs and production time have been minimised. Although modern windows have improved properties with regard to thermal insulation, air tightness and ease of operation, some of the old knowledge is not used or has been lost as a result of industrial production. The Directorate of Cultural Heritage has taken the consequences of this and started a few years ago a training programme aimed at keeping alive the skills needed to producing different building materials and products the old way to ensure proper maintenance and repair of existing buildings but also to maintain and regain knowledge in this area.

Most of the manufacturers of windows in Norway participate in a voluntary control of windows, The Norwegian Door and Window Control. Window types which are to be registered in this approval system must satisfy a set of requirements based on experience and laboratory testing. Important properties relate to materials, design, thermal insulation (U-values), air tightness and condensation risk. Old windows often do not satisfy all these requirements.

This paper presents a life cycle assessment of maintenance and upgrading of existing old windows as opposed to replacement of new and modern windows with regard to use of resources and environmental impact. The examples demonstrate the differences in impacts between the way craftsmen selected and used the timber and today's modern industrial production.

2 Windows in existing buildings

Figure 1 shows the most common types of windows from the middle of the 16th century till 1960. Windows, often the most prominent features of a building, were firmly connected to the architecture of the period in which the building was erected. These periods lasted for decades and changes were slow and developed through several generations. To change windows may change the whole appearance of the building. It is therefore not enough to find a satisfactory technical solution when improving the windows. Any changes must be aesthetically acceptable as well. Old buildings should therefore retain windows with the same visual appearance as the original. This means that even profiles of mullions, frames and crossbars are important details. Examples of such details are shown in figure 3.

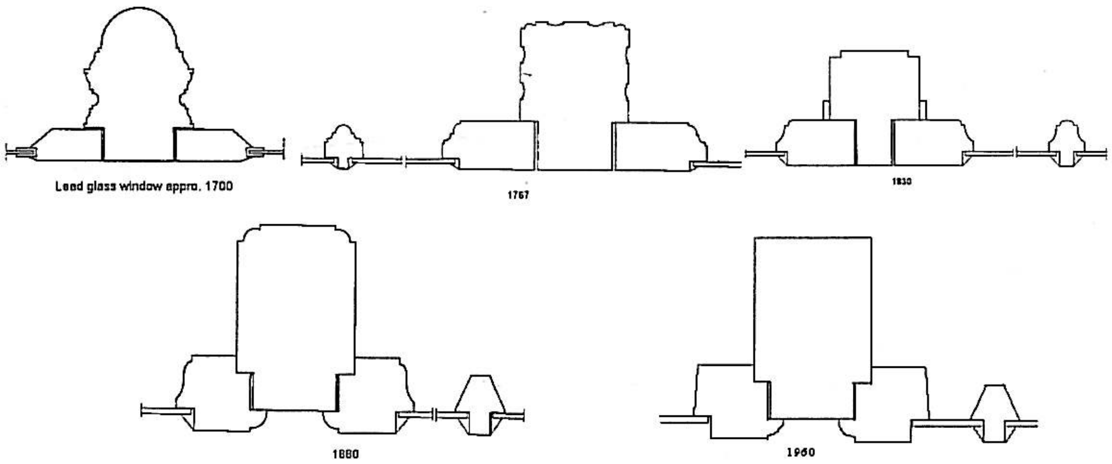


Figure 3
Profiles of frame, sash, mullion and crossbar.

Owners of older buildings manage a part of our cultural heritage. Windows are in this context the most vulnerable building component. Because we often replace them uncritically the copy may in many cases be a poor substitute. Many old windows were made of first class materials which is the reason why we find windows that are more than 250 years old and still in excellent condition. Today we have examples which show that damages are more extensive on windows from 1930 than on windows which are hundred years older. A skilled carpenter/joiner can very often repair and upgrade old windows as an alternative to replacement and in that way preserve and document the original windows.

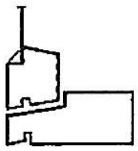
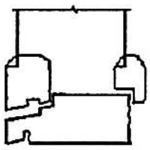
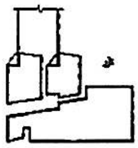
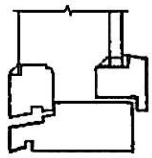
Before the 18th century it was common to nail the window sash to the frame. Later sashes were often hinged to the mullion to enable the window to be opened outwards. A major part of the heat loss from the building was caused by air leakage around windows and doors and from floor to wall and wall to roof joints. Windows in many old buildings still have single pane windows with a poor U-value and a high air leakage.

Windows from before the second world war were normally produced with no space between sash and frame to accommodate a weather strip. As a consequence an air leakage of 10 -15 m^3/m^2h can be expected under normal conditions for single frame windows where no steps have been taken to avoid draught through the joints between sash and frame. If weather strips are used correctly, the air leakage can be reduced to 0.5 m^3/m^2h. This will have considerable effect on the heat loss. It will also reduce condensation and therefore increase the durability of frames, mullions and bars.

To reduce the heat loss from single pane windows it has been common to add an extra set of inner windows with one, later two panes as shown in table 1. These windows (or sashes) were often not hinged and therefore not opened during winter. They were normally removed and stowed away during summertime. Later, particularly when double glazed inner windows were introduced, these windows were hinged to open inwards while the original window generally opened outwards.

Noise problems, particularly in urban areas have led to a demand for windows with improved acoustic properties. An extra sash also improve the noise reduction figures significantly.

Table 1
Examples of typical older Norwegian wooden windows. Thermal insulation - the U-value representing glazing, sash and frame.

	1	2 (~1930)	3 (~1940)	4(~1970)
Window construction	Single pane in single frame	Single pane window with inner frame - single pane	Coupled frame two panes	Single pane window with inner frame - two panes
				
U-value W/m^2 K	4.7	2.6	2.7	2.0
Air leakage* m^3/m^{2}h	10 - 15/~1**	< 1**	< 1**	< 1**
R*** dBA	24	30-32	28-30	36

*) pressure difference 50 Pa
**) with weather strips
***) Noise reduction, based on 4 mm panes

Moisture is the most common cause of damage to old windows both from the outside (rain, frost and dew) and from the inside (condensation or ice formation). The most exposed parts of the window is the sill and the lower parts of sash and frame. The head jamb is normally well protected and on the side jambs the water will flow down. Wood which is exposed to moisture and not allowed to dry out will quickly decay. The end grain is particularly vulnerable to rot. Wood which have been allowed to dry out is usually in a good condition even if the surface may seem grey and weather beaten.
Rust may occur on screws, hinges and fittings. Wear and tear will effect the hinges and opening mechanism.
Common glazing compound based on linseed oil will in time be hard and brittle, open up for moisture penetration and accelerate the risk of wood rot.
Even with high quality wood, the condition of old windows today is very much a function of the quality of painting and other maintenance carried out in the past.

3 New and modern windows

Production of modern windows has become a fully automated industry. The market can offer many types of windows with different properties. As in the past the size, form and positioning of the windows are important architectural features. Present production methods makes it easy to satisfy individual wishes to form and size without additional costs.
Three types of materials are used in windows in Norway today. Wood is the most common material followed by aluminium and plastic. Aluminium and plastic windows require less maintenance than wooden windows, but aluminium has high thermal conductivity and thermal expansion. Some aluminium windows have problems in satisfying the thermal insulation requirements in the building code, particularly for dwellings. Aluminium windows are used mostly in commercial and industrial buildings.

Plastic windows are always strengthened with metal profiles since the stiffness of the plastic itself is poor.

Windows made of wood combined with an external weather shield of aluminium (aluminium cladding) have become common to increase the durability. All new wooden windows are in some way or another artificially preserved. Figure 4 shows examples of windows manufactured of different materials.

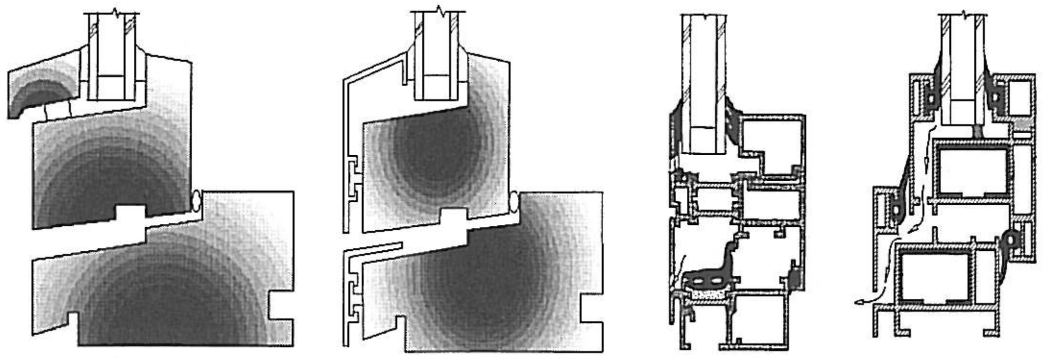


Figure 4
Windows of wood, wood combined with aluminium shield, aluminium and plastic.

Norwegian windows must stand up to the extremes of high Atlantic winds, driving rain, snow, ice and inland temperatures which may vary from +35 °C in summer to -50 °C in winter.

User requirements and performance criteria defined by the Norwegian Door and Window Control have brought about a number of new and better solutions in recent years. Air leakage and penetration of driving rain has been minimised. Tests carried out by The Norwegian Door and Window Control shows that air leakage for new windows is less than 1.5 $m^3/h\ m^2$ (test pressure of 700 Pa), while the requirement is 10 $m^3/h\ m^2$. Compared to old windows better solutions have been developed in facilitating cleaning and in allowing the window to open outwards or inwards. A locking mechanism which prevent children from falling out and prevent burglary has also been developed.

The most common reasons for people to change their windows are to get better thermal insulation, easier window cleaning or to reduce traffic noise. It is mainly the glass which determine the thermal insulation properties. But it is the frame, sash and not least the installation details which separate the best from the poorest. The obvious advantage of a low U-value is the saving of money and the increase in comfort, but the window opening can also be increased to allow more light into the room without jeopardising the heat loss. The risk of condensation due to low temperatures on the inner pane, radiation and cold draft from the window will also be reduced with better U-values.

The glass used in window manufacturing today is produced according to the float-process which was invented in the 1950's. The panes are normally divided in double glazing and energy saving glass. Ordinary double glazed windows (1.2 m x 1.2 m) has a U-value of 2.8 $W/m^2\ °K$ while the best energy saving glass on the marked has a U-value close to 0.8 $W/m^2\ °K$.

Table 2
U-values, air leak and noise reduction of new Norwegian wooden windows (1.2 m x 1.2 m).

	U-value w/m^2 °K	air leakage* m^3/m^2 h	noise reduction dB(A)
Double glazing	2.8	0-0.5	28-29
Energy saving glass	1.8	0-0.5	28-29
Energy saving glass with argon	1.6	0-0.5	28-29

*) pressure difference 50 Pa

A major part of old apartment buildings in Oslo were build in the period from 1880 to 1890. It was in the 1970's that the process of replacing windows from these buildings started. These replacements were justified as an energy saving measures with roots to the oil crisis in 1971-72 rather than a necessity caused by deterioration.
There is no doubt that air pollution from heating, traffic and industry has increased considerable after the Second World War thus reducing the expected life time of windows. Today service life of new windows varies from 10 years to 70-80 years, but it has been common to calculate with 30 years as the service life of today's windows.

4 Life cycle assessment

4.1 General

Sustainable development has become a fashionable phrase used and misused in many contexts since it was launched in connection with the work carried out by the World Commission on Environment and Development known as the Brundtland report «Our common future» in 1987.
This work was followed up by the Conference in Rio de Janeiro in Brazil in 1992 which stated that the main reason for an increased depreciation of the global environment was a none sustainable production- and consumption pattern especially in the industrialised countries.

The Brundtland Commission has defined sustainable development as a development which meets the needs of the present without compromising the ability of future generations to meet their own needs. This means to keep today's consumption of resources, emissions to air and water and waste disposal within the limits given by nature itself.

One way producers and users can acquire knowledge about how products influence the environment is to carry out life cycle assessments. Life cycle assessment is a method to determine the environmental impact of a product throughout the product's whole life cycle.
A life cycle assessment looks at a product system and assess the health, the environment and the use of recourses of this system throughout the product's life cycle.
A complete life cycle assessment consists of four steps as shown in fig 5.

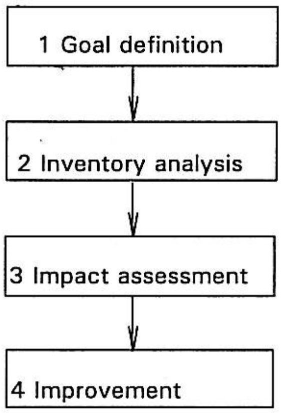


Figure 5
Life cycle assessment.

In step 1, the goal and scope of the investigation is defined and also the limitations of the investigation.
Step 2 consists of collecting data and carrying out an analysis of material- and energy flow within the limitations defined in step 1.
Step 3, impact assessment is divided into three subgroups:

1. Classification - all emissions are classified in impact categories
2. Characterising - the contributions from each impact category are estimated from quantitative or qualitative methods
3. Assessment, valuation and weighting the impact from each impact category

In step 4 the results of the investigation are analysed and «hot spots» pointed out. Finally proposals for action to reduce the environmental impacts are considered.

4.2 Impact categories

In a complete life cycle assessment all emissions must be considered for determining the total impacts. It is common under step 3 to divide the classification into three main categories. These categories are subdivided as shown in table 3.

Table 3
Impact categories

MAIN CATEGORY	SUB CATEGORY
1. Use (depletion) of resources	1.1 Energy and materials
	1.2 Water
	1.3 Land
2. Human health	2.1 Toxicological impacts
	2.2 Physiological impacts
	2.3 Psychological impacts
	2.4 Diseases due to biological organisms
3. Ecological impacts	3.1 Global warming potential
	3.2 Depletion of stratospheric ozone
	3.3 Acidification
	3.4 Eutrophication
	3.5 Formation of photo-oxidants
	3.6 Eco-toxicological impacts
	3.7 Impacts on biological diversity

In this paper the following impact categories are assessed.

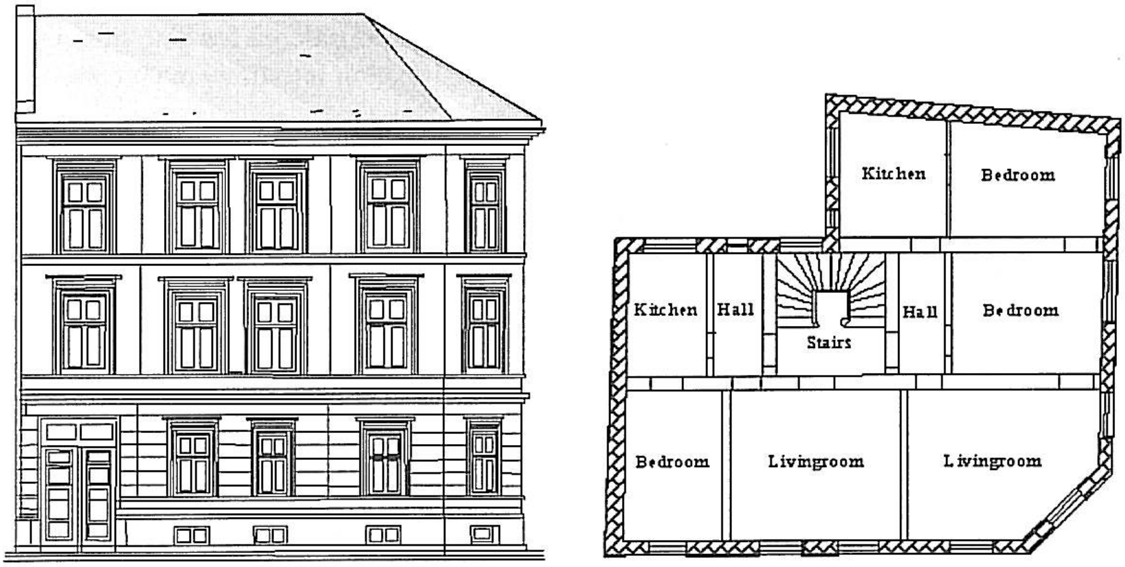
1. Global warming potential from CO_2- emissions
2. Acidification caused by emissions of SO_2 and NO_x
3. Photo-oxidant formation from VOC
4. Eutrophication from NO_x
5. Depletion of fossil resources

Valuation and weighting between the categories is not be carried out. This is a controversial issue which can not be based on scientific methods alone.

4.3 Window alternatives

The life cycle assessment of windows is carried out with reference to an existing building from 1887, figure 6. The three storied block of flats is made of brick masonry. The building has a ground floor of 154 m², an average room height of 3.1 m and is located in Oslo. . The building has a window area of 57 m². The single glass windows in this building were replaced by to pane coupled windows in 1982. The old windows of the building had a service life of 95 years.
The U-values of the external walls, ground floor and top ceiling are, 1.2 - 0.5 - 0.6 W/m² °K.

Figure 6
Three store building



A life cycle assessment of different window alternatives is carried out. The functional unit is chosen to be all the building's window and 90 years. Four windows alternatives are assessed and compared with the old windows. Table 4 shows the specification of the old windows and the four alternative windows.

Table 4
Properties of different window alternatives

	Old windows	Old windows with single glazed inner frame	Old windows with double glazed inner frame	Coupled double glazed windows	Energy windows with Argon
Number of glasses	1	2	3	3	2
U-value W/m^2 °K	4.7	2.6	2.1	2.0	1.8
Air infiltration m^3/m^{2}h	0.15	0.15	0.1	0.1	0.1
Solar factor	0.87	0.78	0.70	0.70	0.60

Table 5 shows the materials used in the different window alternatives. The mass specification includes cut-offs and replacements for a period of 90 years.
It is assumed that new windows exposed to external climate must be replaced twice, while inner frames do not need to be replaced during this period.

Table 5
Materials used throughout the life time of different window alternatives

	Old windows with single glazed inner frame	Old windows with double glazed inner frame	Coupled double glazed windows	Energy windows with Argon
	kg	kg	kg	kg
Timber	17	25	161	188
Glass	13	26	117	78
Steel	2	2	6	10.5
Insulation between frame and wall	0.00	0.00	0.21	0.21

Calculation of the energy consumption has been carried out according to Norwegian Standard 3031, "Calculation of the energy and power demand for heating and ventilation in buildings". In addition a hot water consumption of 12.6 GJ per year is assumed. Table 6 shows the calculated energy consumption of the different window alternatives of the building. The saved energy for the different window alternatives are shown in table 7. This is the saved energy for the total life time (90 years) compared to the old windows.

Table 6
Calculated energy consumption of different window alternatives

	Old windows	Old windows with single glazed inner frame	Old windows with double glazed inner frame	Coupled double glazed windows	Energy windows with Argon
	GJ/year	GJ/year	GJ/year	GJ/year	GJ/year
Transmission	125	110	106	106	104
Ventilation	19	19	19	19	19
Infiltration	9	9	6	6	6
Hot water	13	13	13	13	13
Lighting	11	11	11	11	11
Equipment	10	10	10	10	10
Free energy(sun, persons)	-32	-31	-30	-30	-30
Total energy consumption	153	139	133	133	132

Table 7
Saved energy compared to the old existing windows for a period of 90 years

	Old windows	Old windows with single glazed inner frame	Old windows with double glazed inner frame	Coupled double glazed windows	Energy windows with Argon
	GJ	GJ	GJ	GJ	GJ
Saved energy	0	123	176	175	187

5 Use of resources, energy consumption and environmental impact connected to maintenance, upgrading or replacement of windows

The building, shown in figure 6, is heated with electricity. No emissions of CO_2, SO_2, NO_x and VOC is taking place as a result of heating the building, because energy for heating is based on hydropower. The energy and environmental account, split in consumption of electricity and fossil energy, and emissions of CO_2, SO_2, NO_x and VOC (volatile organic compounds) are shown in table 8. The table covers all the phases from quarrying, production, use and demolition. As seen from the table the energy used in the building during the life time of the windows (90 years) account for almost all the energy consumption in this assessment. The major environmental impact, however, is caused by the production of the windows.

Table 8
Energy and environmental impact from windows for a period of 90 years

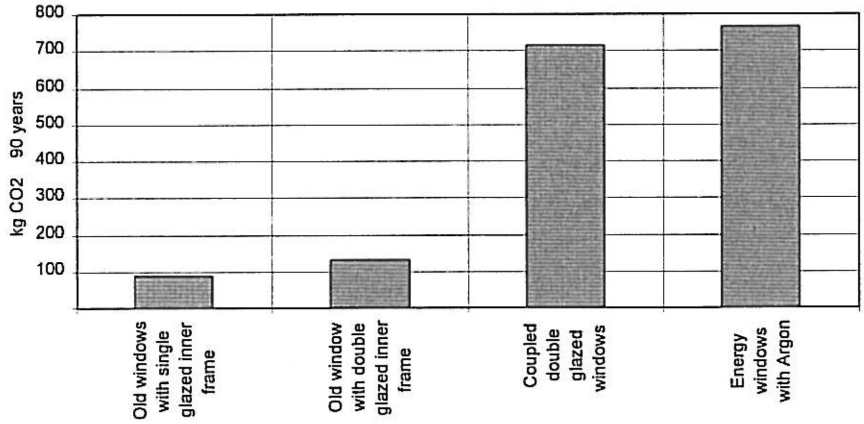
	Electricity GJ	Fossil GJ	Total GJ	CO_2 g	SO_2 g	NO_x g	VOC g
Old windows with single glazed inner frame							
Production and replacement	1	3	4	87058	451	1953	182
Use	12524		12525				
Dismantling/Demolition		0	0	114	0	2	0
Total	12525	3	12529	87172	451	1955	182
Old windows with double glazed inner frame							
Production and replacement	2	5	8	130196	793	3594	247
Use	11993		11993				
Dismantling/Demolition		0	0	194	0	3	1
Total	11995	5	12001	130390	794	3597	248
Coupled double glazed windows							
Production and replacement	12	26	39	713457	3978	17451	1408
Use	12002		12002				
Dismantling/Demolition		0	0	1057	1	17	3
Total		26	12041	714513	3979	17468	1411
Energy windows with Argon							
Production and replacement	13	21	35	766169	3450	13750	1678
Use	11878		11878				
Dismantling/Demolition		0	0	1032	1	16	3
Total	11891	21	11913	767201	3451	13766	1681

5.1 Environmental impact from different window alternatives

5.1.1 Global warming potential

The global warming potential is calculated in CO_2 equivalents. Figure 7 shows the emissions of CO_2 for the four window alternatives. The global warming potential, expressed in CO_2 equivalents, is approx. seven time higher for new windows (coupled windows with double glazing and windows with energy glass) that for the old windows with inner frames.

Figure 7
Global warming potential

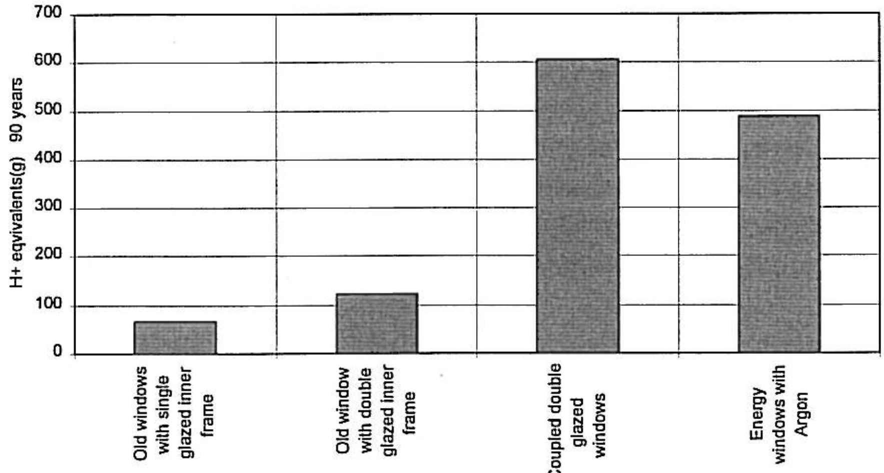


The figure shows that new windows with energy glass contribute most to the global warming potential.

5.1.2 Acidification

Acidification is expressed as H+-equivalents and the effect is calculated from the emissions of SO_2 and NO_x. SO_2 contributes with 2 mol of protons for each mol of sulphur and NO_x contributes with 1 mol of protons for each mol of nitrogen. It is assumed that NO_x consist of 50 % NO and 50 % NO_2.

Figure 8
Acidification

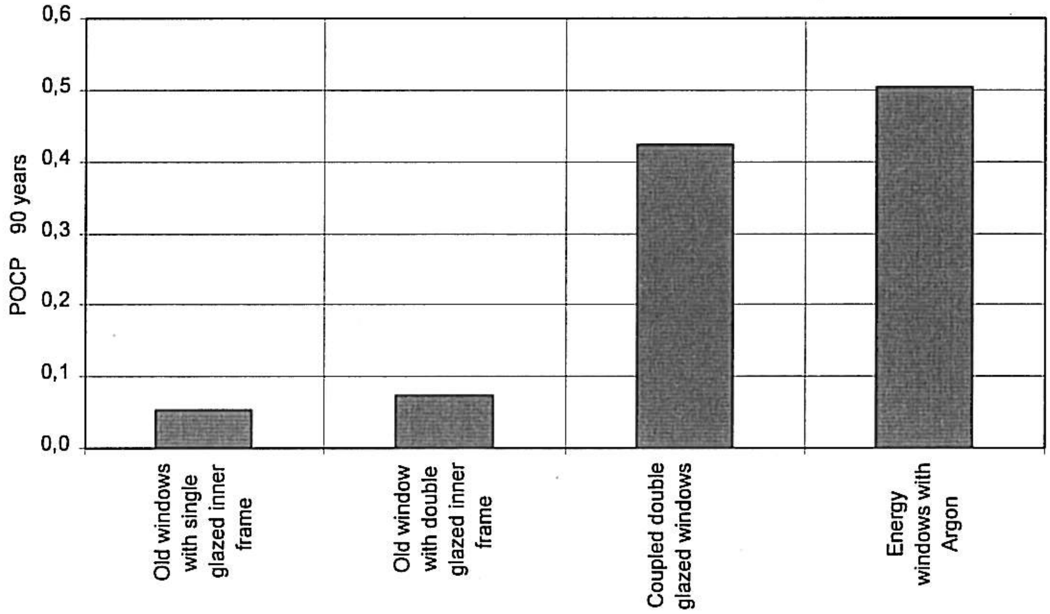


The figure shows that the acidification, expressed in H+ equivalents, is highest for new coupled window with double glazing followed by a new window with energy glass. The contribution from new windows is four to seven times higher than from the old windows with inner frames when it is assumed that all the NO_x emissions contribute to acidification.

5.1.3 Photo-oxidant formation

Photo-oxidant formation, i.e. the production of ozone under the influence of solar radiation, is expressed in POCP (Photochemical Ozone Creation Potentials) also called ethene-equivalents. Formation of ozone is caused by either VOCs or NO_x. In assessing the different window solutions only the VOC emissions have been considered.

Figure 9
Photo-oxidant formation

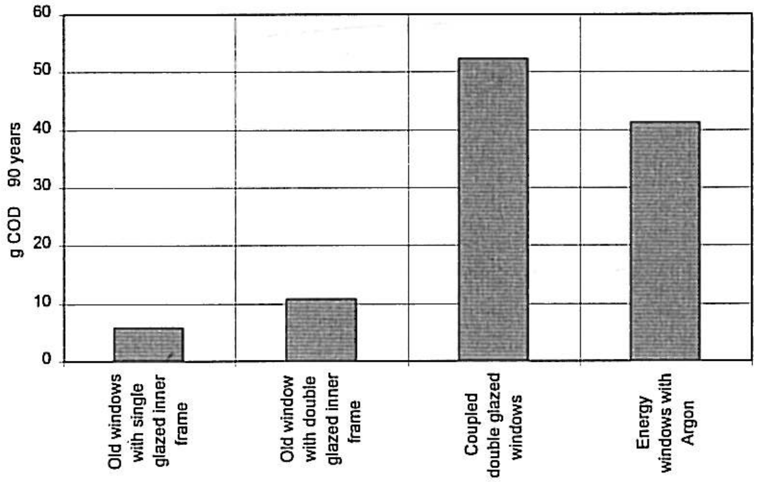


The figure shows that the photo-oxidant formation potential is eight to ten times higher for new windows than for the old ones with inner frames. Since the emissions of VOC mainly come from transportation and the total weight of new windows is six to nine times higher than for the old windows with inner frames this could be expected.

5.1.4 Eutrophication

Eutrophication is considered only for emissions of NO_x. Their contribution to eutrophication can be calculated to COD (chemical oxygen demand). It is assumed that NO_x exist as NO_2 and the consumption of oxygen is 8.6 mol for each mol of nitrogen.

Figure 10
Eutrophication

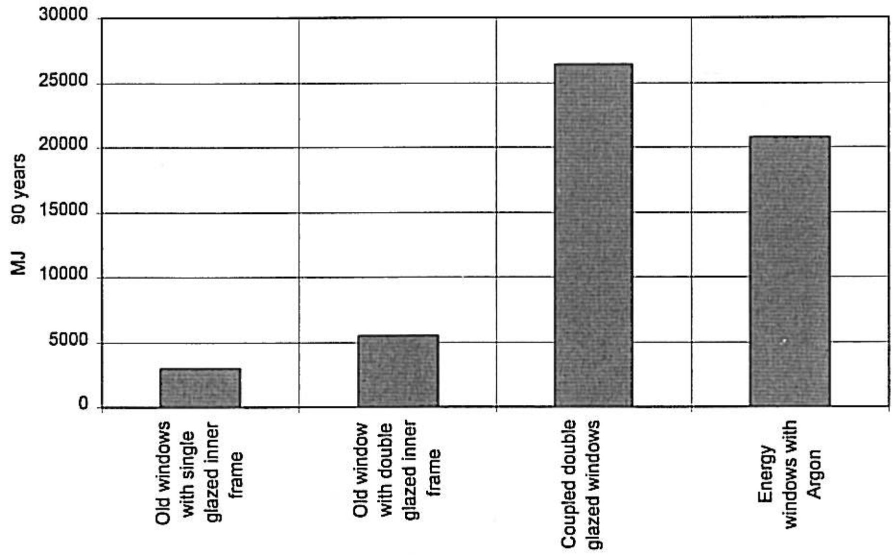


The new windows contribute several times more to eutrophication of land, water and water systems than old windows with inner frames. Also in this case it is the potential effects that have been calculated.

5.1.5 Depletion of fossil fuel

Depletion of fossil fuel is expressed in MJ and is a result of fuel consumption in production and transport. Figure 11 shows that the consumption of fossil recourses for production and replacement of new coupled windows with double glazing is approx. six time higher than for using the old windows with an inner frame with single glass.

Figure 11
Depletion of fossil fuel



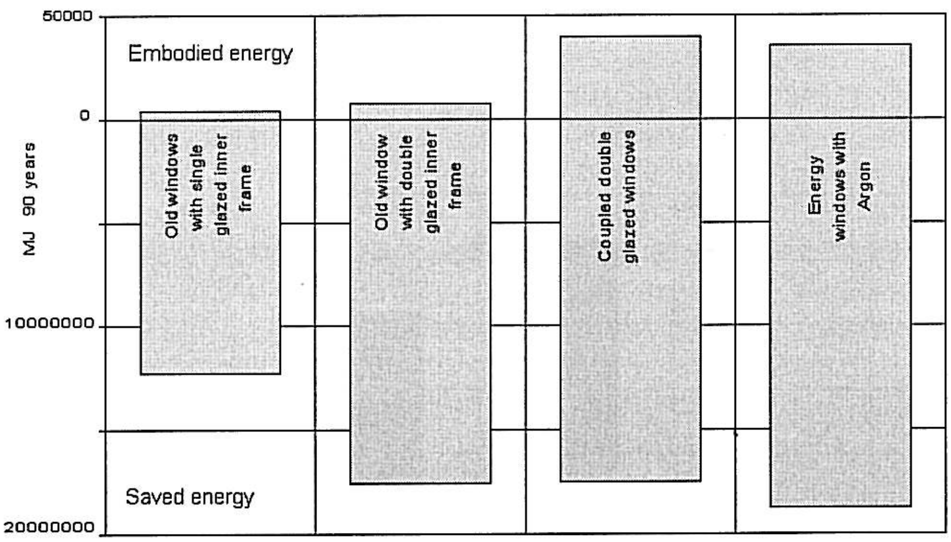
Of all the solutions considered the new coupled windows with double glazing have the highest consumption of fossil fuel. This is explained by highest glass weight. The production of glass have the highest fossil consumption of the materials a window consist of.

5.1.6 Total energy aspects

Calculations show that new windows have the highest embodied energy, figure 12. The energy saved compared to the old windows (Table 7) for the different window alternatives is highest for the new windows with energy glass. The embodied energy, constitute only from 0.5 % to 2.5 % of the saved energy of the different window alternatives.

The total energy situation for the four alternatives show the best result for the new windows with energy glass followed by the old windows supplied with inner frames with double glazing. The difference of the total energy consumption for a period of 90 years between new windows with energy glass and old windows with inner frame with double glazing is, however, less than 1 %. This alternative would therefore appear to be very attractive with relation to the work done by The Directorate of Cultural Heritage since old windows with double glazed inner frames will not affect the exterior of the building and have an energy loss of the same magnitude as the windows with energy glass. With regard to environmental impact the old windows with inner frame and double glazing will be approx. six times better than the windows with energy glass.

Figure 12
Total energy situation



The difference in embodied energy between new windows with energy glass and old windows supplied with doubled glazed inner frame is saved by using new windows with energy glass over a period of four to five years. This alternative will have, however, higher environmental impact.

The best alternative taking into account both the total energy consumption and the environmental impact for a period of 90 years, will be to equip the inner frame with energy glass rather than double glazing.

5.1.7 Waste handling

Most of the materials from demolition of windows are still transported to waste disposal sites. Shortage of resources and environmental considerations may require reuse and recycling also in connection with demolition of windows. The waste from demolition of windows is wood, glass, aluminium, steel and plastic. Recycling processes for metals, glass and plastic are already available. Wood which normally is preserved and painted may represent a problem since it will require special treatment before reused or burned. The energy consumption and environmental impact from demolition of windows will be small compared to the remaining materials of a building.

6 Conclusions

The durability of windows depends on materials used, construction, maintenance and weather exposure. There are many examples which show that the lifetime of old windows, where old craftsmen's knowledge has been applied, may exceed 250 years, while new windows, in practice, will have a shorter lifetime. The most common reasons for people to replace their windows is either to achieve better thermal insulation, easier service and maintenance or to reduce traffic noise and not a necessity caused by deterioration. The replacement of old windows may have serious negative effects on the appearance of a building even if the new windows are near copies of the existing ones.

A life cycle assessment of new coupled windows with double glazing, new windows with energy saving glass and old windows supplied with an inner frame with single or double glazing, have been carried out with reference to an existing block of flats from 1887. It is assumed that the building is heated with electricity and that the electricity is produced from hydropower with no emissions to the air. The chosen functional unit is all the building's windows and 90 years.

The results of this assessment show the smallest environmental impact if the old windows are supplied with an inner frame with single glass followed by old windows supplied with an inner frame with double glazing. This is with respect to all the environmental categories (global warming potential, acidification, photo-oxidant formation, eutrophication and consumption of fossil fuel) over a period of 90 years.

The total energy consumption for a period of 90 years, however, is higher for the old windows supplied with inner frame with single or double glazing than with new windows with energy glass. For the chosen building the calculations show approx. 15 % higher total energy consumption in the user phase for the building with old windows (single pane) compared to new windows with energy glass.

From the point of view of the Directorate of Cultural Heritage the replacement of old windows with copies has never been a good solution. As pointed out, one normally ends up with solutions that are only near copies, because new technical solutions are introduced, occasionally new materials and almost always new dimensions compared to the original ones.

The Cultural Heritage Authorities have for many years recommended keeping (if necessary repairing) the old windows and adding an inner frame as the best solution to improve the technical standard in order to meet modern requirements. This keeps the exterior appearance intact, while at the same time the effect of the old irregular pane when looking out from the inside will be preserved. The same goes for the original materials and the technical knowledge embodied in the construction of the window will also be kept.
This solution has been criticised for not being effective enough with regard to energy saving. The study shows that the total energy consumption over a life time of 90 years is only 1 - 5 % higher for the recommended solution compared to new windows. This must be considered a very low price for maintaining the aesthetic values and the authenticity of the original. When we also take into consideration the higher degree of negative environmental impact caused by the production of new windows, the conclusion is clear: There is no good argument for replacing old windows in normal condition with new ones, instead of attaching an inner frame.

7 References

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