SINTEF

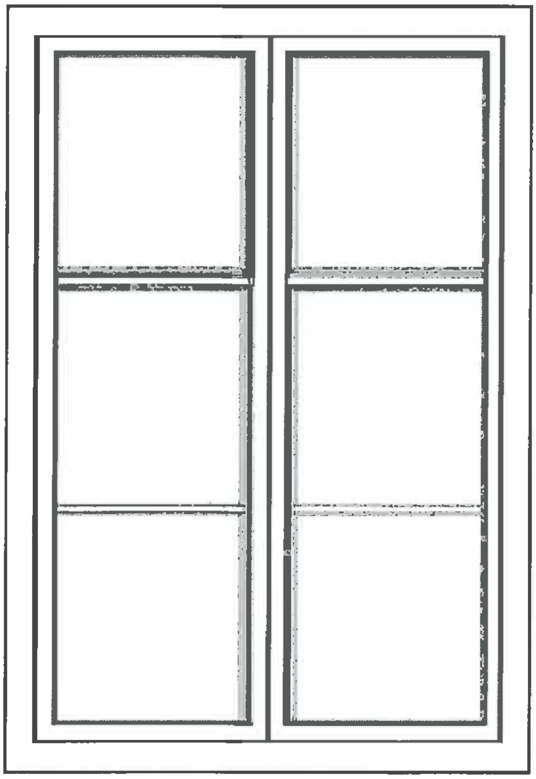
3D1110 - Open

Report

Energy efficient windows with cultural value

Measurements and calculations

Author(s)
Anders Homb, Sivert Uvsløkk



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Anders Homb, Sivert Uvsløkk

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PREPARED BY
Anders Homb and Sivert Uvsløkk

SIGNATURE

CHECKED BY
Lars Gullbrekken

SIGNATURE

APPROVED BY
Jonas Holme

SIGNATURE

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Contents

1. Summary

SINTEF Byggforsk has conducted a project for the Norwegian Directorate for Cultural Heritage and Enova to document relevant properties of energy-efficient windows with cultural value. The starting point for the work was an older type of double-casement window with simple casements and a single glass layer divided into three panes by horizontal glazing bars. Two types of secondary casement were produced, one with single glazing and one with double glazing. Measurements and calculations were carried out with two different spacings from outer glass to secondary casement. The project involved the following:

- Measurement of U-value
- Calculation of U-value with exact and simplified method
- Measurement of air flow and self-drying potential
- Measurement and assessment of sound insulation
- Heat balance calculations

The measurements show that a U-value of between 1.5 and 1.6 W/m²K can be achieved for an old window with a secondary casement with single-pane glass with a hard coating. With double glazing in the secondary casement, a U-value of below 1.0 W/m²K can be achieved. Small air openings in the outermost casement are necessary to enable moisture that enters between the casements to dry out again. Measurements with and without air openings show that moderate air openings do not affect the U-value of the window. Calculations of U-values by the exact method show good agreement with measured values. U-values were also calculated for a number of combinations using the exact method.

Sound insulation measurements showed that the airtightness of the joints between casement and window frame is decisive for the result. Thus tightness is far more critical for sound insulation than for the U-value. The measurements also show, as one might expect, that an increase in the gap between external glass and glass in the secondary casement results in a substantial improvement in sound insulation. If optimal sealing is achieved, a high level of sound insulation can be achieved with a limited weight of glass in the secondary casement.

Calculation of the heat balance shows that the overall energy requirement for a standard small house with floor, walls, roof and installations that have been upgraded to TEK10 standard, will be approximately 50% lower when the windows are upgraded from single glazing to double- or triple glazing with the use of secondary casements.

2. Background and aims

Several hundred thousand buildings in Norway are registered as having been erected before 1900. If pre-war buildings are included, there are therefore a substantial number of buildings that still have original windows of historic cultural value. Each style epoch has its own types of windows with their own characteristic features: formats, pane divisions, details, mouldings and other decorative accessories that form part of an architectural whole. Windows were simple to begin with, with panes mounted in lead frames and from the 1700s in wooden casements with putty rebates. After a while it became usual to set in an extra, secondary casement, with an extra glass. The manufacture of opening windows with coupled casements began in about 1900, while the first double glazing with clear glass and air in the cavity came onto the market in about 1960. For a more detailed overview, see SINTEF Byggforsk (1989).

Although many of the older windows have been replaced, many are still preserved. This applies to both villas and many blocks of flats. The original windows generally have poor thermal insulation, and refurbishing these windows can therefore potentially save a substantial amount of energy; see for example Grytli (2004).

By installing a secondary casement with the correct double glazing, the U-value of a refurbished window can become at least as low as that of a new window with the same number of layers of glass. The

U-value in the middle of the glazing is a little higher in a refurbished old window because one of the cavities is filled with air instead of argon, but this extra heat loss is more than outweighed by the fact that the U-value of the frame/casement portion is lower in a window with a secondary casement than a new window with ordinary casements. The reason for this positive frame/casement effect is that the gap between inner and outer glass surface is larger in a window with a secondary casement than in a new window with an ordinary, single casement. This means that the heat has a longer way to go through frame and casement. The heat technology benefits of secondary casements and low-emission glass are also described in Fredlund (1999) and Energiforsatsgruppen (2010).

Before windows are replaced, careful consideration should be given to whether the old windows can be repaired and/or upgraded to satisfy today's requirements with respect to comfort, thermal insulation and airtightness. Preserving any original windows that still exist will be an important aim when refurbishing buildings with a status protected or of cultural value. The background to preserving old windows has been described by the Cultural Heritage Management Office of Oslo Municipality (1999). Upgrading of windows by means of secondary casements with good glazings is a relatively simple measure that should also be considered for buildings other than those with cultural value. It may also be profitable when the windows are otherwise in good condition, particularly if it is not necessary to upgrade the façade/outer cladding. Measures of this kind may therefore be highly effective and result in a marked reduction in the use of energy in the existing buildings.

Upgrading windows to make them energy-efficient presents a number of challenges. This applies to both upgrading principles, choice of solution, rational production and the financial aspect; see also SINTEF Byggforsk (2000) and (2004). Documentation of thermal transmittance (U-value) and sound-insulation properties is demanded with respect to technical properties and upgrading potential. Sound insulation applies to buildings in areas with traffic. For a more detailed overview, see SINTEF Byggforsk (2006). This means good sealing and moisture-proofing must be ensured, and the possibility of external condensation and need for maintenance must be considered.

The aim of this project was to document thermal insulation potential, air-tightness and sound insulation of a typical old window that is upgraded with a secondary casement with glazings of various kinds. The results of the project may contribute to the preservation of more original windows in old houses, make upgrading a simpler choice, result in buildings with far more energy-efficient windows and generally improve comfort.

3. Test windows

When planning the project, we had discussions with Marte Boro at the Directorate for Cultural Heritage and Roger Hugnes at Enova as to which type of window should be chosen as the point of departure for the upgrading, and which general solutions were relevant. In order to carry out measurement of U-values according to normal standards, the window had to have an external width of a maximum of 1.23 m and a height of a maximum of 1.48 m.

There are a large number of varieties of windows that were usual in the 1800s or first half of the 1900s. Our discussions ended with our agreeing to take as our starting point a double-casement window with single glass divided into three panes by horizontal glazing bars. This is a common window variant of the 19th century (empire window). We regarded it as difficult to find an original old window that we could use, and it was therefore decided to build a new window of this type, but according to old drawings. The window was manufactured by Trebetong AS, and we had a meeting with Karl R. Johansen to clarify details of the structure of the window, the secondary casements and appurtenant details.

The window was manufactured with an external width of 1.119 m and height of 1.449 m. A drawing of the window is shown on the first page of the report. It was decided to produce two sets of secondary casements:

- Secondary casement 1 with single glazing, E4, with hard coating, emissivity 0.17, facing the cavity. Pane codes for the glazing:
  4-74-E4 (secondary casement in middle position) and 4-144-E4 (inner position).
- Secondary casement 2 with double glazing, E4-16Ar-E4, with two low-emission coatings. The outermost pane with a hard coating, emissivity 0.17, facing the outer cavity, and the innermost pane with an ordinary energy coating facing the pane cavity (innermost cavity) filled with argon gas.

Explanation of the pane codes that are also used in the result diagrams:

- The figures give the thickness in mm of glass and cavity measured from the outside.
- The letter E indicates that the glass has a low-emission coating (heat-reflecting coating).
- The letters Ar or Kr after the cavity thickness indicate that the cavity is filled with argon or krypton.
- Argon and krypton are inert gases that insulate better than air.
- In our calculations we have assumed that cavities containing inert gas are filled with 90% gas and the remainder air.
- When there are no letters after the cavity thickness, the cavity is filled with air.

In order to investigate the significance of the location of the secondary casement, the U-value of the window was measured with the secondary casements placed in both middle and inner position. The window frame had an internal rebate as a stop for the secondary casement when the latter was placed in the middle position (closest to the outer casement). When the secondary casement was in the inner position, it had a stop against strips that were screwed to the window frame.

A horizontal section of the original window is shown in Fig. 3.1. Figs 3.2a and 3.2b show horizontal sections of an upgraded window with secondary single-glazed casement with the casement in two positions, while Figs 3.3a and 3.3b show corresponding horizontal sections of the window with a secondary casement with double glazing.

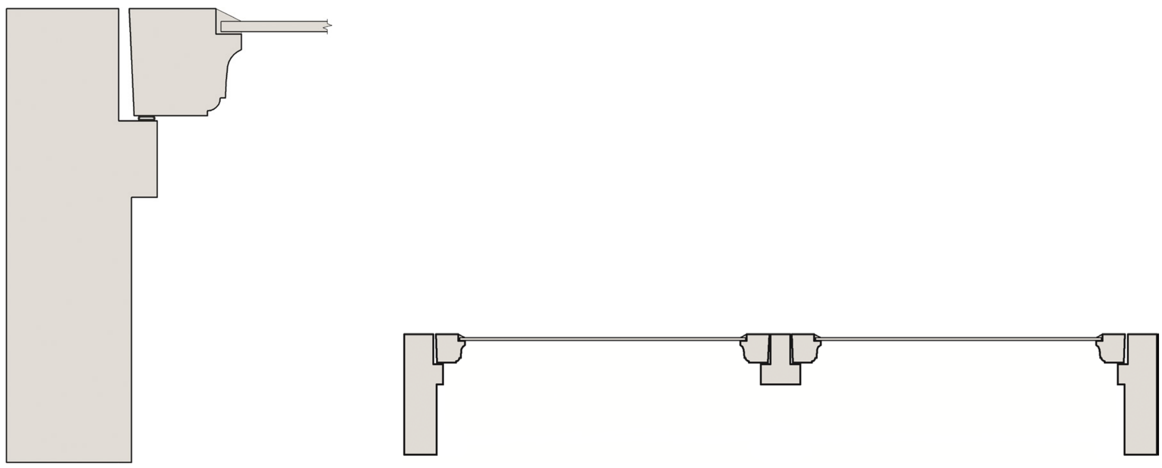


Figure 3.1
Horizontal section of original window with external frame width 1119 mm and height 1449 mm.
The frame profile is 179 mm deep and 48 mm wide. The profile of the external casement is 42 mm deep and 44 mm wide.

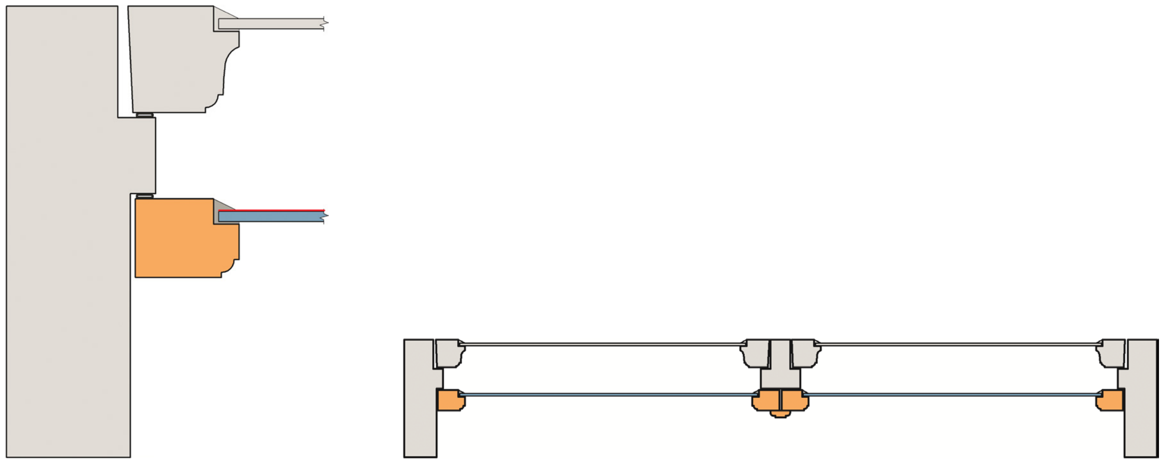


Figure 3.2a
Horizontal section of upgraded window with secondary casement in middle position.
The single glass in the secondary casement has a low-emission, hard coating, marked here with a red line on the outer side facing the air cavity. The profile of secondary casement 1 is 31 mm deep and 44 mm wide. The cavity between the panes is 74 mm deep.

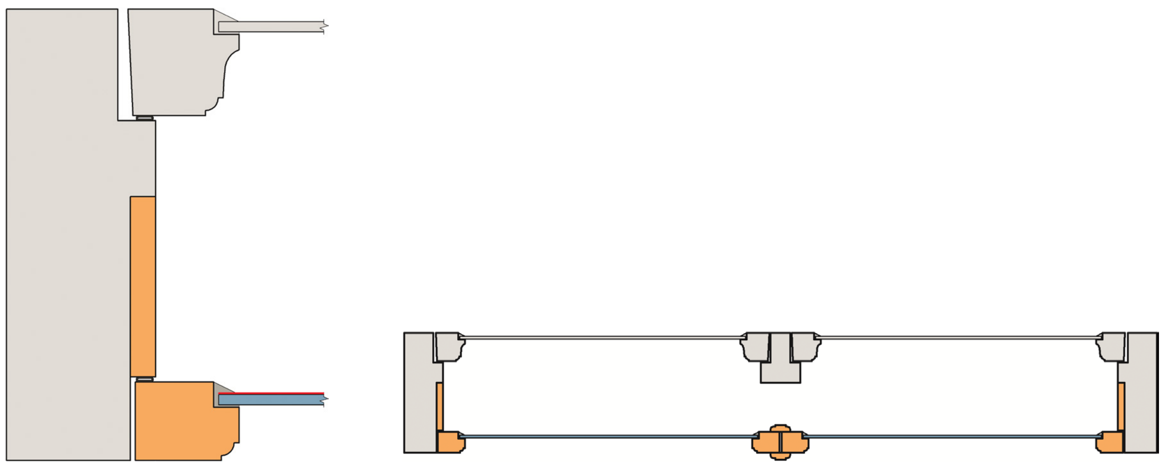


Figure 3.2b
Horizontal section of upgraded window with secondary casement 1 in inner position.
The single glass in the secondary casement has a low-emission, hard coating, marked here with a red line on the outer side. The cavity between the panes is 146 mm deep.

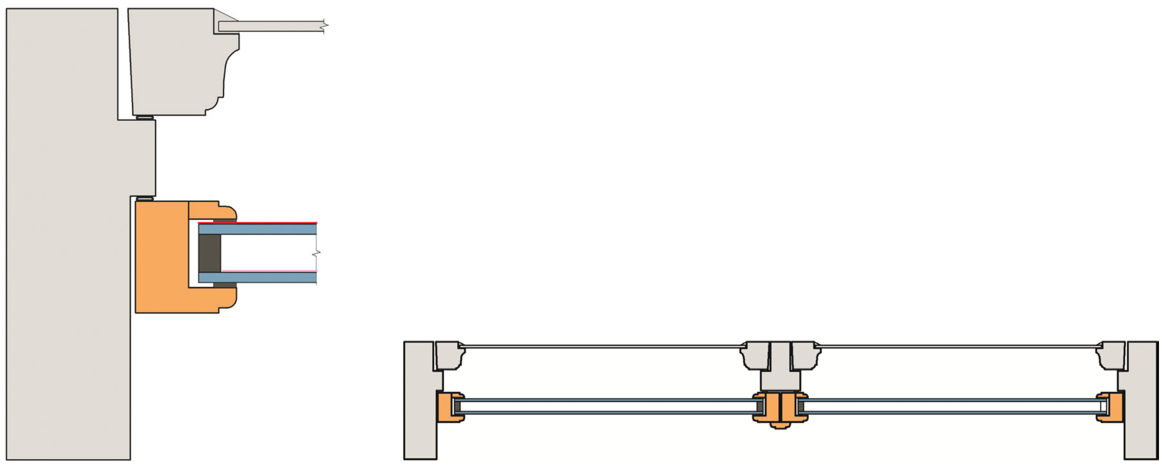


Figure 3.3a
Horizontal section of upgraded window with secondary casement 2 in middle position.
The double glazing in the secondary casement has low-emission coatings on both panes, a hard coating, red line, on the outer side of the outermost pane and an ordinary coating, pink line, on the innermost pane facing the small cavity. The profile of the secondary casement 2 is 44 mm deep and 44 mm wide. The cavity between the single glass and the double glazing is 74 mm deep.

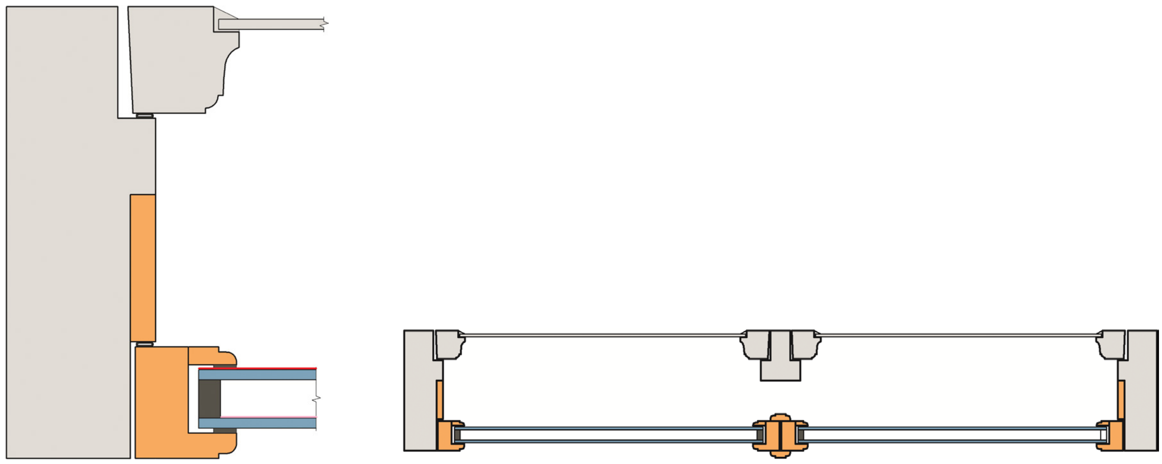


Figure 3.3b
Horizontal section of upgraded window with secondary casement 2 in inner position.
The double glazing in the secondary casement has low-emission coatings on both panes, a hard coating, red line, on the outer side of the outermost pane and an ordinary coating, pink line, on the innermost pane facing the cavity. The cavity between the single glass and the double glazing is 134 mm deep.

4. U-value

4.1 Measuring U-values

The U-values of the five varieties of window were measured by use of a hot-box at SINTEF Byggforsk's laboratories in Trondheim. The measurements were carried out according to NS-EN 12567-1 (2010). A brief description of the measuring method is given in the Appendix (Chapter 10). The concept 'U-value' or thermal transmittance is used as a standardized measure of how easily a building element allows heat transmission. The U-value is expressed in W/m²K and indicates the heat flow per unit area, unit of time and unit of temperature difference between the hot and cold sides of the structure (1 K = 1°C). A well-insulated building element therefore has a low U-value. The U-values measured for the whole window are shown in Fig. 4.1. Temperatures measured on the hot and cold sides of three of the windows are shown in the Appendix (Chapter 12).

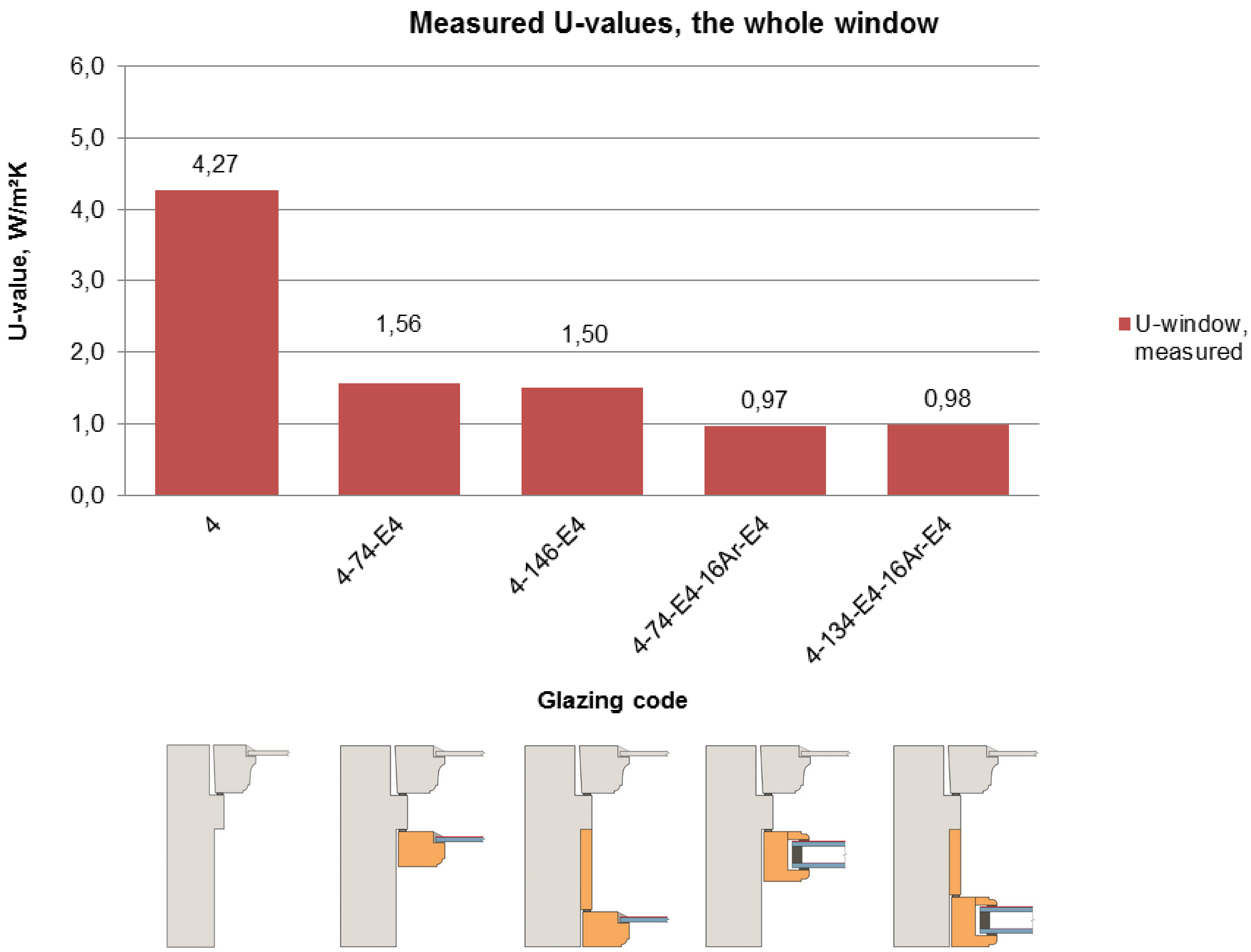


Figure 4.1
Measured U-values for the whole window for the five varieties of window that are shown directly under the diagram. Pane descriptions with thickness of glass and cavity depth are written transversely under the diagram.

The measurements show that a substantial improvement in the U-value is achieved by upgrading an existing window with an extra glazing in a secondary casement. With a double glazing in the secondary casement, the U-value will be lower than 1.0 W/m²K, which is the same level as a new wooden window with a good triple-glazing. Moving the secondary casements from the mid- to the inner position did not result in significant changes in the U-value of the window. Fig. 4.2 shows U-values measured in the middle of the glazing together with U-values for the whole window.

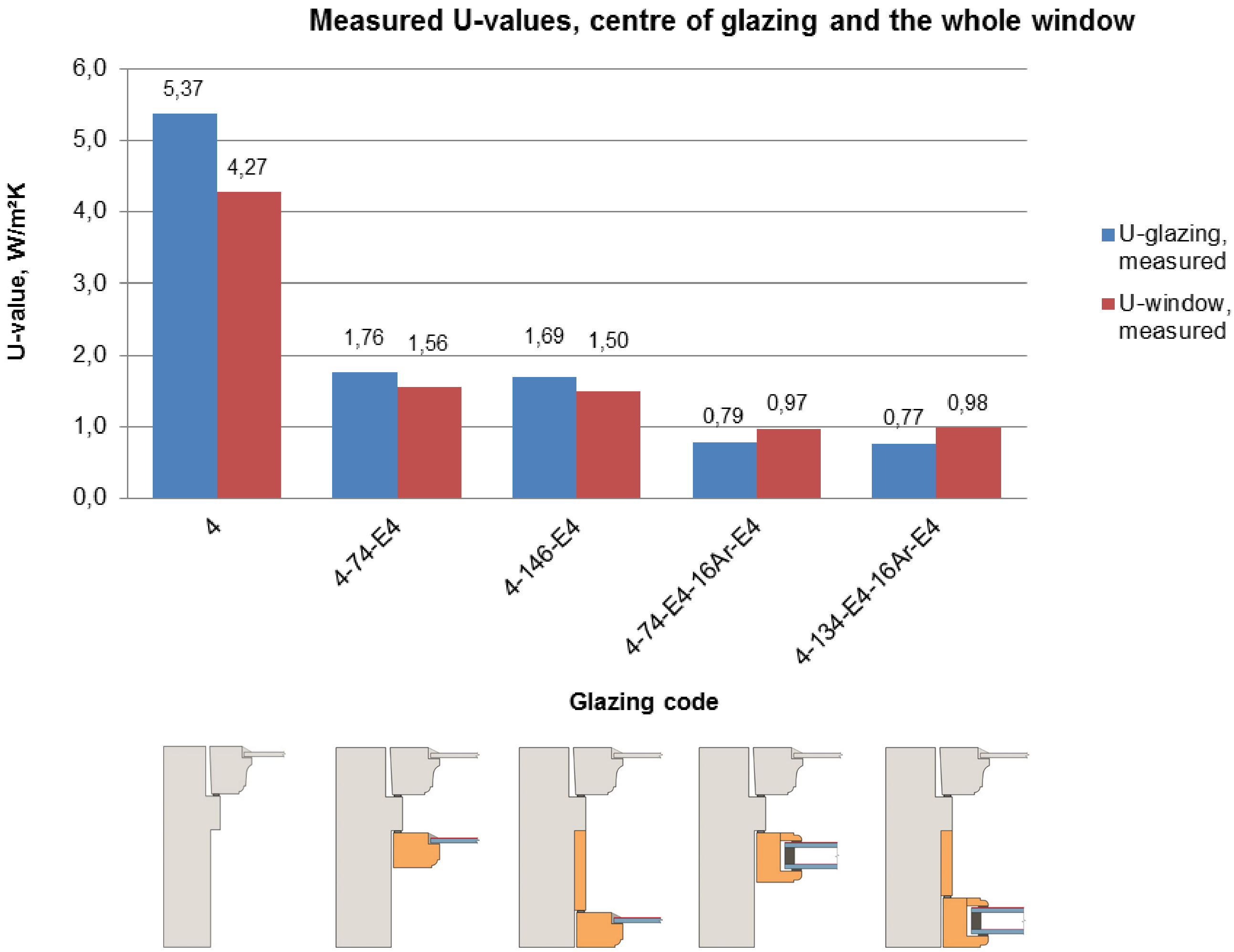


Figure 4.2
U-values measured in the middle of the glazing and for the whole window.

The U-value of the window was measured both with and without air openings in the outermost casement. Air openings in the outer casement are necessary to give the cavity between the casements a certain self-drying potential. Without holes for airing, the moisture that enters between the casements can cause condensation, ice formation and growth of fungus.

Results with and without air openings in the outer casement are shown in Table 4.1.

Table 4.1
Measured U-values, W/m²K, for the whole window without and with air openings in the outer casement

Description	Secondary casement 1 with single glazing		Secondary casement 2 with double glazing	
	Without holes in outer casement	With 2 air holes in each casement and total hole area 0.4 cm² per casement	Without holes in outer casement	With 4 air holes in each casement and total hole area 4.0 cm² per casement
Secondary casement in middle position	1.56	1.56	0.96	0.97
Secondary casement in inner position	1.52	1.50	0.97	0.98

The measurements show that the air opening in the outer casement did not cause any significant rise in the U-value in any of the varieties of window that were investigated.

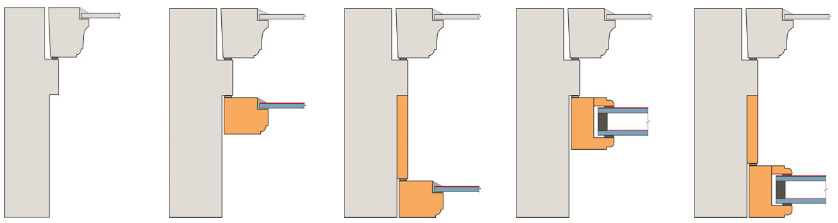
4.2 Exact calculation of U-value

In order to obtain the most accurate calculated U-value, the U-value of the frame and casement profiles, U_F, and the linear thermal transmittance, Ψ_F, must be calculated according to NS-EN ISO 10077-2 using a program for two-dimensional heat flow. We used the THERM 6.3 modeling program. The U-value for the glazing was calculated according to ISO 15099 (2003). A more detailed description of the calculation method is given in Appendix, Chapter 11.

The results of exact calculations of the five window varieties are shown in Table 4.2. The same structure and dimensions are used in the calculations as for the measured varieties; see also Figs 3.1, 3.2 and 3.3.

Table 4.2
Calculated U-values and linear thermal transmittance for the five varieties of windows investigated, exact calculation.

Whole window	**U_W W/m²K**	**4.56**	**1.62**	**1.57**	**0.92**	**0.94**
Glazing	U_G W/m²K	5.75	1.87	1.87	0.77	0.77
Frame-casement	U_F W/m²K	2.27	1.08	0.92	0.97	0.82
Edge-frame	Ψ_F W/mK	0.011	0.0031	0.0026	0.026	0.037
Mullion-casement	U_M W/m²K	2.81	1.21	1.17	0.88	0.88
Edge mullion	Ψ_M W/mK	0.011	0.010	0.012	0.011	0.035



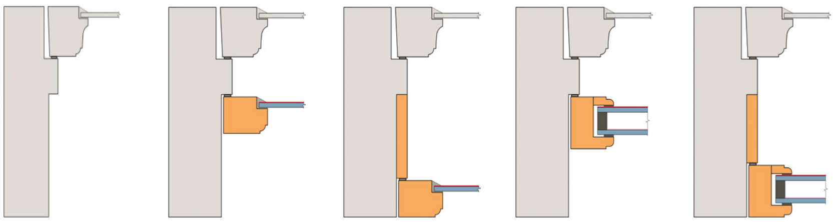
4.3 *Simplified calculation of U-value*

Simplified calculation is performed according to the same principles as exact calculation, but the U-value of frame and casement, U_F, and the linear thermal transmittance, Ψ, are calculated in a simplified manner according to the rules in NS-EN ISO 10077-1 (2006). Here too, the U-value for the pane, U_G, is calculated according to ISO 15099 (2003). The results of previous calculations of outward-opening wooden windows are to be found in Arnesen (2008).

The results of simple calculations of the five window varieties are shown in Table 4.3. The same structure and dimensions are used in the calculations as for the measured varieties; see also Figs 3.1, 3.2 and 3.3.

Table 4.3
Calculated U-values and linear thermal transmittance for the five varieties of windows investigated, simplified calculation.

Whole window	**U_W W/m²K**	**4.19**	**2.01**	**2.01**	**1.28**	**1.28**
Glazing	U_G W/m²K	5.75	1.87	1.87	0.77	077
Frame-casement	U_F W/m²K	1.38	1.26	1.26	1.22	1.22
Edge-frame	Ψ_F W/mK	0.080	0.080	0.080	0.080	0.080
Mullion-casement	U_M W/m²K	1.92	1.57	1.57	1.45	1.45
Edge mullion	Ψ_M W/mK	0.080	0.080	0.080	0.080	0.080



4.4 Comparison of calculated and measured U-values

Calculated and measured values for the whole window, U_W, are shown together in Fig. 4.3, while calculated and measured values for the middle part of the glazings, U_G, are shown together in Fig. 4.4.

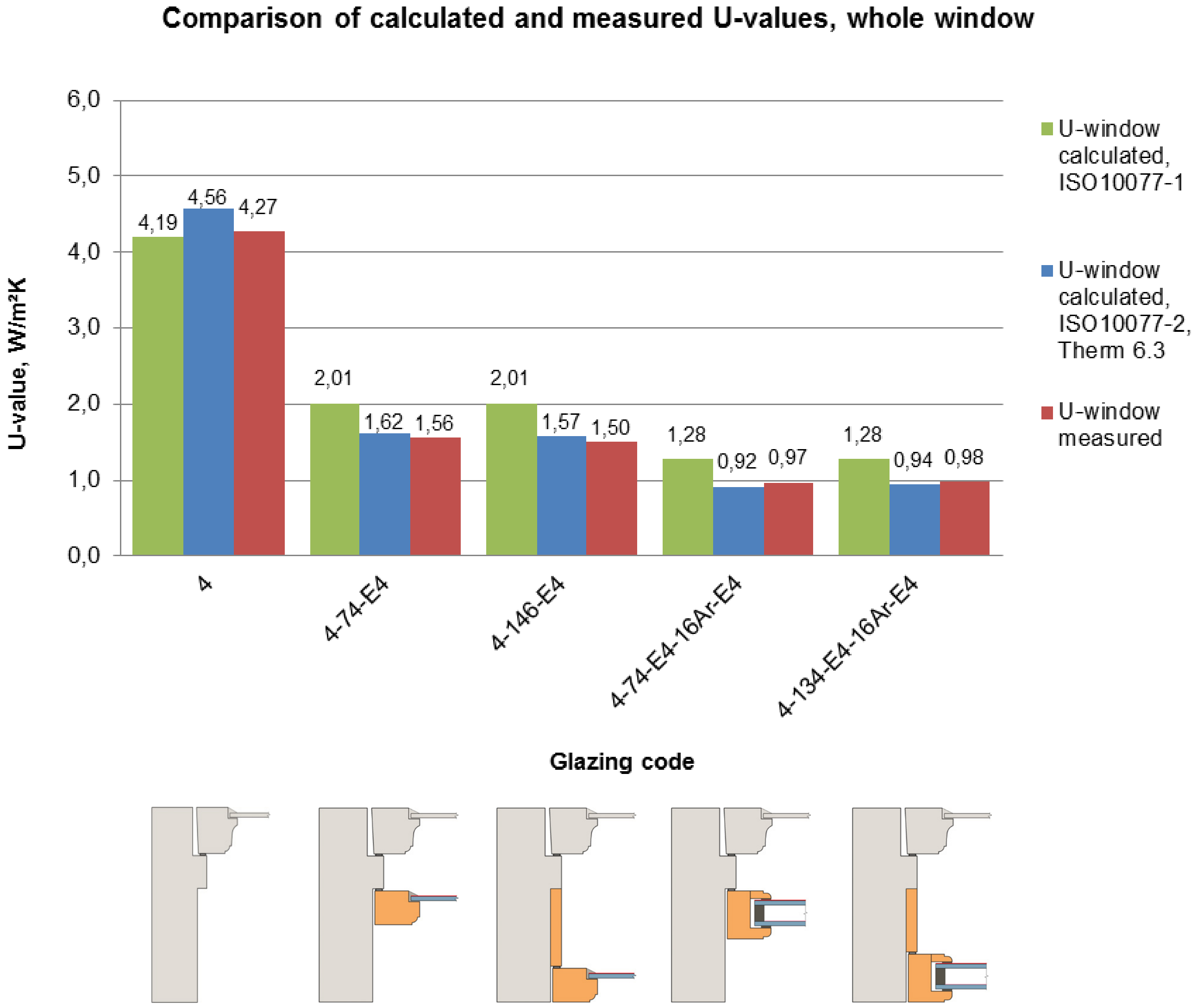


Figure 4.3
Comparison of calculated and measured U-values for the five different windows. The green columns show values calculated by the simplified method; the blue show values calculated by the exact method, while the red columns show measured values.

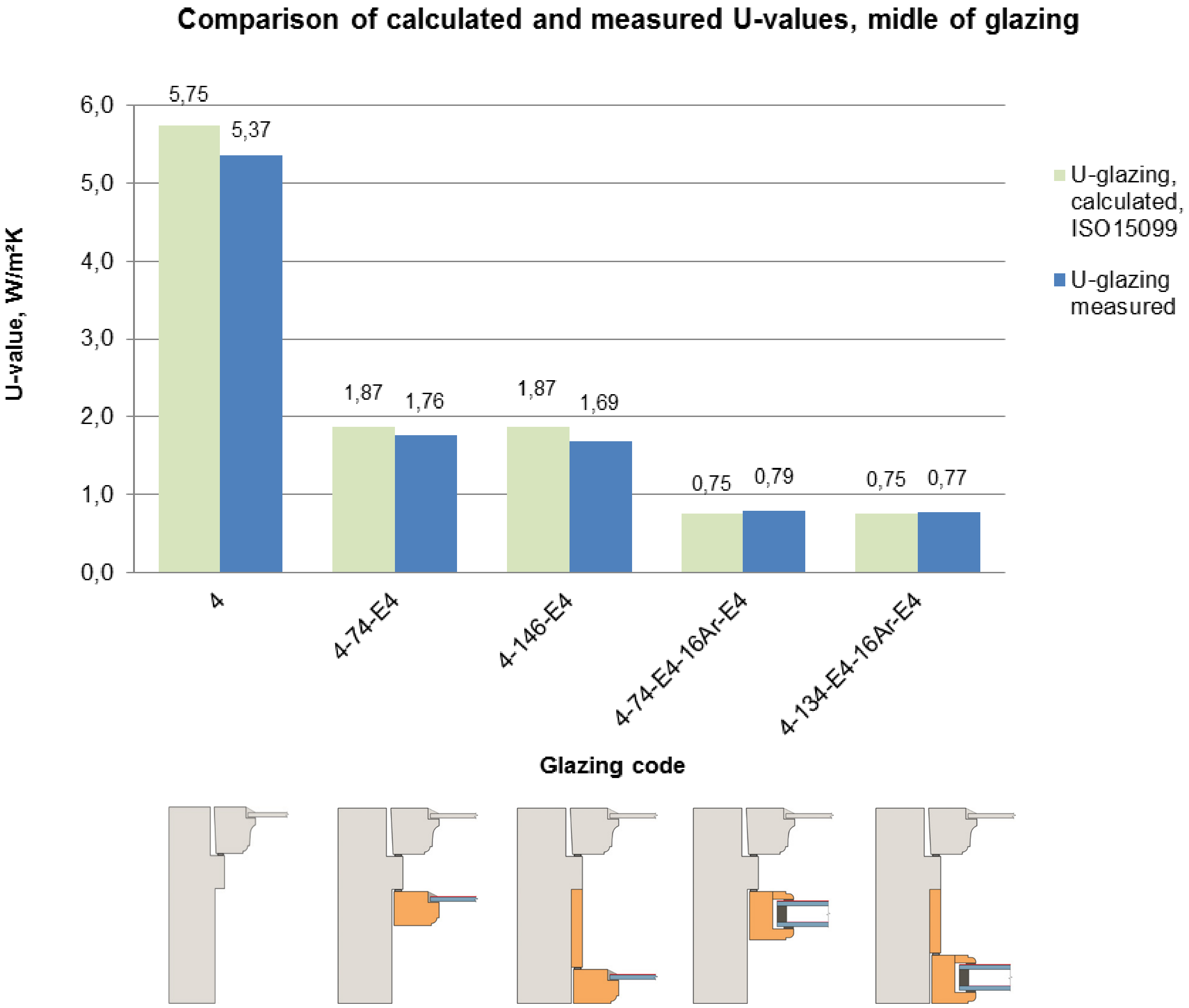


Figure 4.4
Comparison of calculated and measured U-values for the middle portion of the glazing of the five different windows. The pale green columns show values calculated using the exact method and the blue columns show the values measured using a heat-flow meter in the middle of the pane.

5. Air-tightness and self-drying potential

5.1 Measuring air flow

Measuring air flow in the window with only external casements with various air openings was carried out according to the method described in the Appendix, Chapter 10. The windows were delivered with two circular air holes with a diameter of 5 mm in each casement: one hole in the uppermost casement timber and one hole in the lowermost. This proved to yield too little self-drying potential for the cavity between the casements. As described in Chapter 4.1, the U-value was therefore also measured with larger air holes in the outermost casements. Other, larger air holes were made by folding back parts of the sealing strips of the outermost casements. Airflow was first measured with the original circular holes and then only with 10, 20, 30, 40 and 50 mm long openings at all the casement corners. The distance between the casement and the stop in the rebate was measured as 2 mm. The overall hole areas per casement for air flow measurements were therefore 33, 80, 160, 240, 320 and 400 mm².

A selection of the measurement results is presented in Figs 5.1 and 5.2.

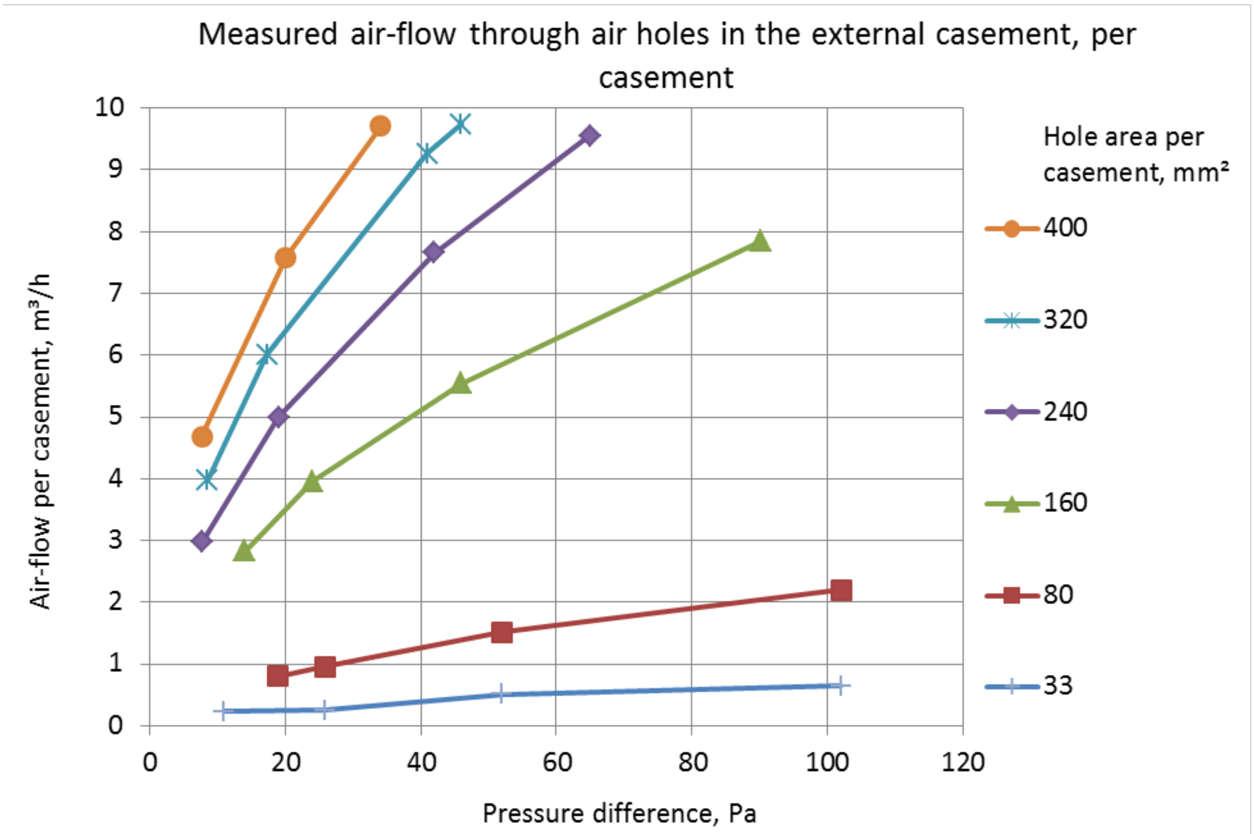


Figure 5.1
The diagram show measured air flow through air holes, per casement

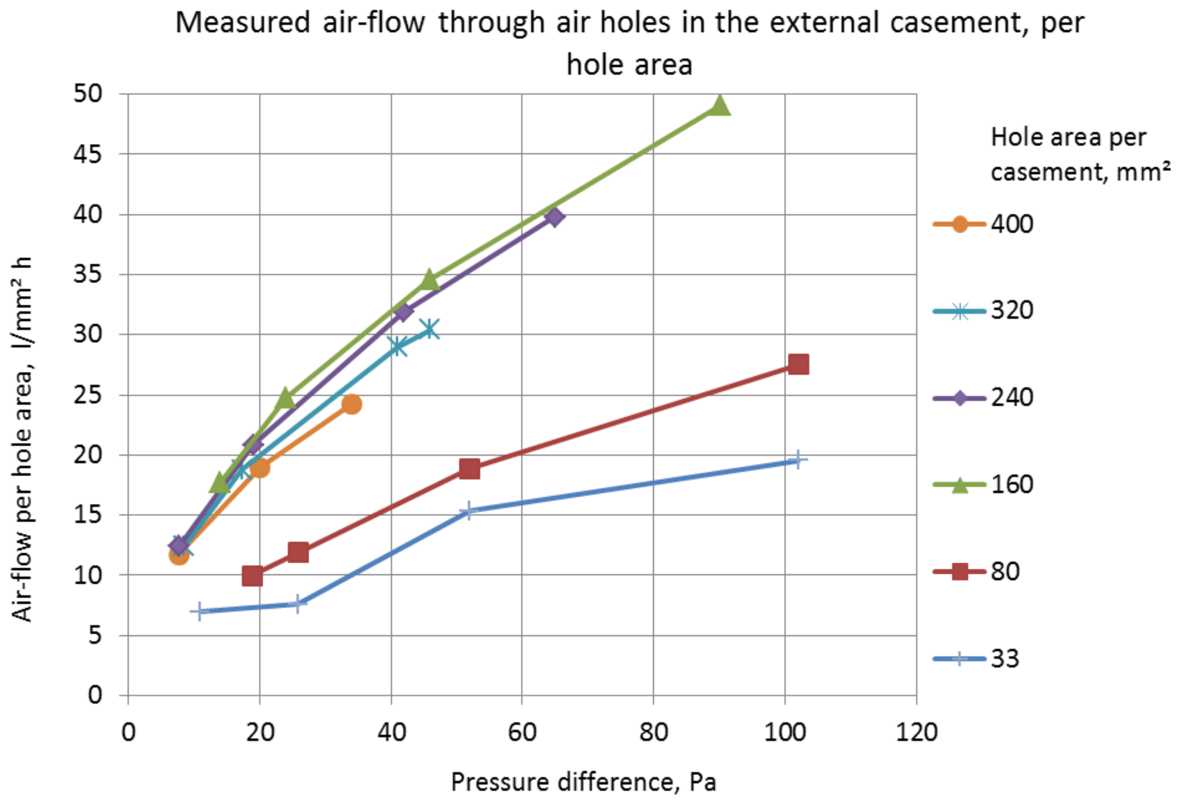


Figure 5.2
The diagram show measured air flow through air holes, per hole area. The curves are based on the same measurement results are shown in Fig. 5.1, but here the values are divided by the overall hole area.

5.2

5.3 Self-drying potential

Measurements have been taken of how moisture from the space between the casements can dry out. This was measured by placing a known amount of water in bowls of aluminium foil between the casements and recording weight reduction as a function of time while the window stood installed in the hot box. The climatic conditions on the two sides of the window in these tests were the same as for the U-value measurements. The inner temperature was 20°C and the outer temperature 0°C. There was an upward air stream with a flow velocity of approximately 4 m/s, parallel with the surface of the window on the cold side during the self-drying tests. In the drying out tests, there was a horizontal air slit with a length of 50 mm and width of 2 mm at all the casement corners. The total hole area was about 400 mm² per casement. The window had secondary casements with double glazings in the middle position. The results of the self-drying tests are shown in Figs 5.3 and 5.4.

The need for self-drying will vary, depending on a number of factors, but primarily on how air-tight the secondary casements and sealing strips around them are. The supply of moisture into the space between the casements takes place primarily through leakage of moist indoor air out through non-tight sealing strips around the secondary casements. In the space between the casements the air is cooled and releases moisture in the form of condensation on the outermost, coldest glass. This takes place primarily during the cold part of the year and when the outdoor temperature fluctuates substantially from day to night.

Removing a few cm of the sealing strips at the top and bottom of the outermost casement is a simple and effective means of achieving a certain self-drying potential so as to avoid condensation in the space between the casements. In order to reduce the possibility of precipitation entering through the same openings, the openings at the top should be made in the vertical sealing strips and the openings at the bottom in the horizontal strips. In our view, an opening area of about 60 mm² at each casement corner will be sufficient in most cases. In places that are exposed to entry of rain or snow, one can try without openings. If there is condensation between the casements, one cm at a time of the sealing strips can be cut away until the condensation problem disappears.

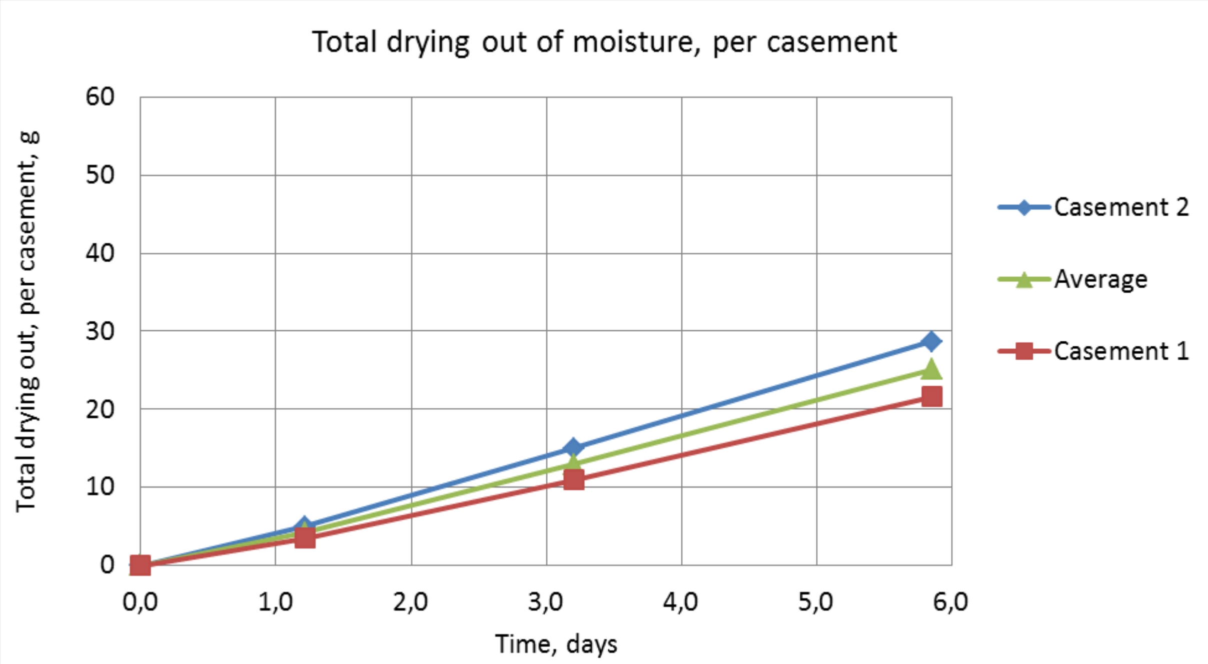


Figure 5.3
The diagram shows measured drying out of moisture per casement. There was an air opening of 50 mm x 2 mm at each casement corner, a total of 400 mm² per casement, during the test.

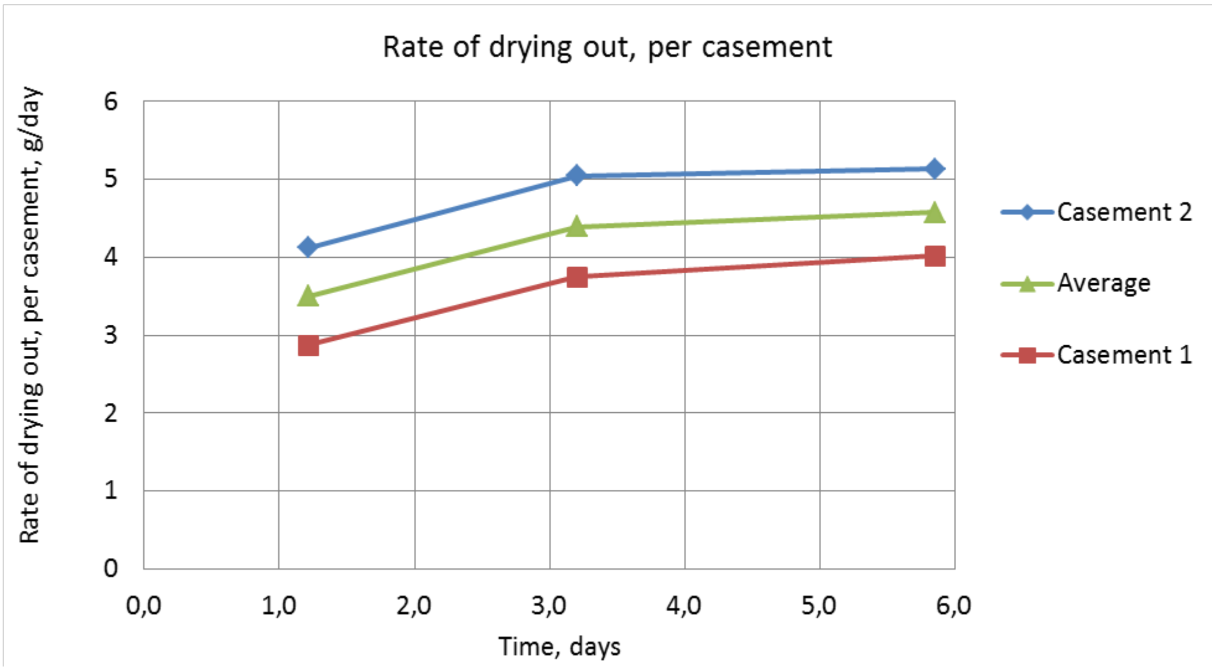


Figure 5.4
The diagram shows measured drying out rate per casement. There was an air opening of 50 mm x 2 mm at each casement corner, a total of 400 mm² per casement, during the test.

6. Sound insulation

6.1 Basis

The sound reduction index, R (dB) is used to describe the airborne sound insulation of a structure, i.e. how good the sound insulation is with respect to speech, music, traffic noise etc. The standardized frequency range for such measurements and calculations is from 100 to 3150 Hz. The weighted sound reduction index, R_w (dB), is a single number rating for sound reduction figures measured in this frequency range. Because our hearing perceives sounds down to about 20 Hz and because traffic noise (for example) contains a lot of energy under 100 Hz, it is recommended and usual to increase the frequency range down to 50 Hz. In order to describe how good the building element is with respect to traffic noise, account is taken regarding the sound energy distribution as a function of frequency. A spectrum adaptation term is therefore used, a conversion index for a standard road traffic spectrum (based on a velocity of 50 km/h), C_{tr} for the frequency range 100-3150 Hz and $C_{tr,50-5000}$ Hz for an expanded frequency range. The higher the R_w values, the better a building element's insulation of airborne sound. When the C_{tr} values are low, insulation against traffic noise and/or low frequencies is good. Measurement of the sound insulation of the window was carried out according to NS-EN ISO 140-3 (2005). For further details, see Appendix, Chapter 10. The measurements of airborne sound insulation were carried out at SINTEF Byggforsk's sound laboratories in Oslo.

A window is a composite structure with many components. In acoustic terms, windows are therefore complex building elements. Sound transmission takes place partly through interaction between the different components and partly through individual components, for example glass, casements or joints. The measured values will always represent the overall sound transmission, which means that cavities and glass thicknesses, for example, may determine the reduction index in one frequency range and the sealing strips in another frequency range.

6.2 Measuring sound insulation

Fig. 6.1 shows measured sound reduction index for windows with single glass in existing casement and with secondary casement. For the measured variant with secondary casement there is a gap of 146 mm between the glass in the outer and secondary casement, see also Figs 3.2 and 3.3. More detailed measurement results are given in the Appendix, Chapter 12.

Both measurement curves show that there is sound leakage at high frequencies which is due to insufficient sealing. For windows with single glazing only, there is also a low reduction index at 250 Hz. Both windows were measured with artificial sealing and in both cases the R_w value improved, by 1 and 2 dB respectively. Both measurements show a low reduction index at 100 Hz. We assume that this is due to sound transmission through the gap between casement and frame when the sealing mechanism is not good enough or has too little mass.

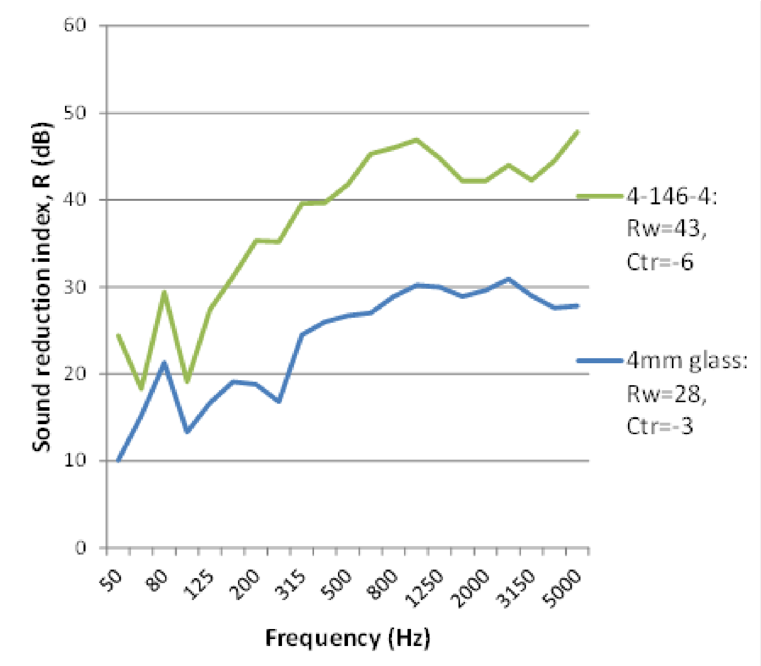


Figure 6.1
Sound reduction index for window with single glass in both existing and secondary casement. Sealing strips as on delivery.

Figure 6.2 shows measured sound reduction index for the types of windows with double glazing in the secondary casements. When the secondary casements are in the middle position there is a gap of 74 mm between the glass in the outer and secondary casement. When the secondary casement is in the inner position there is a gap of 134 mm between the glass in the outer and secondary casement, see also Figs 3.2 and 3.3. More detailed measurement results are given in the Appendix, Chapter 12.

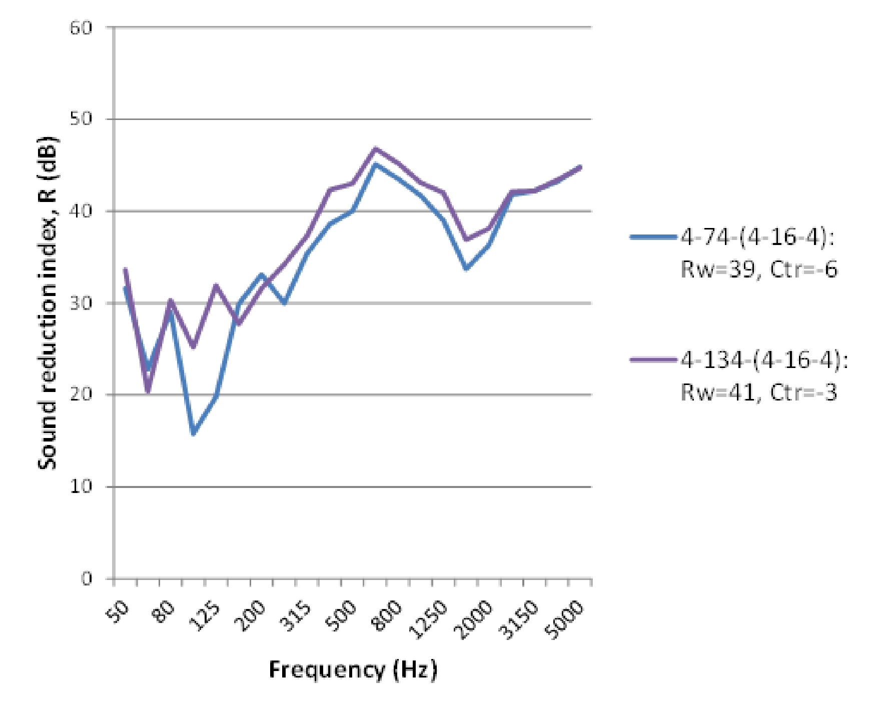


Figure 6.2
Sound reduction index for window with double glazing in secondary casement. Sealing strips as on delivery.

Both measurement curves show that there is sound leakage at high frequencies (about 2000 Hz) which is due to the sealing not being good enough. Measurements of windows with secondary casement in the outer position show very limited reduction figures in the frequency area 100-125 Hz. This is largely due to sound transmission through the gap that exists between casement and frame when the sealing mechanisms is not good enough or has too little mass. This is far less visible with the secondary casement in the inner position, i.e. when the gap between the sealing mechanisms is substantially wider. Low reduction figures at 63 Hz and 200-250 Hz are largely due to resonance because of closed cavities (double/triple wall resonance) for the cavities of 74/134 mm and 16 mm respectively. All the windows were also measured with artificial sealing. Fig. 6.3 shows the original window and the window with secondary casement in inner position without and with artificial sealing.

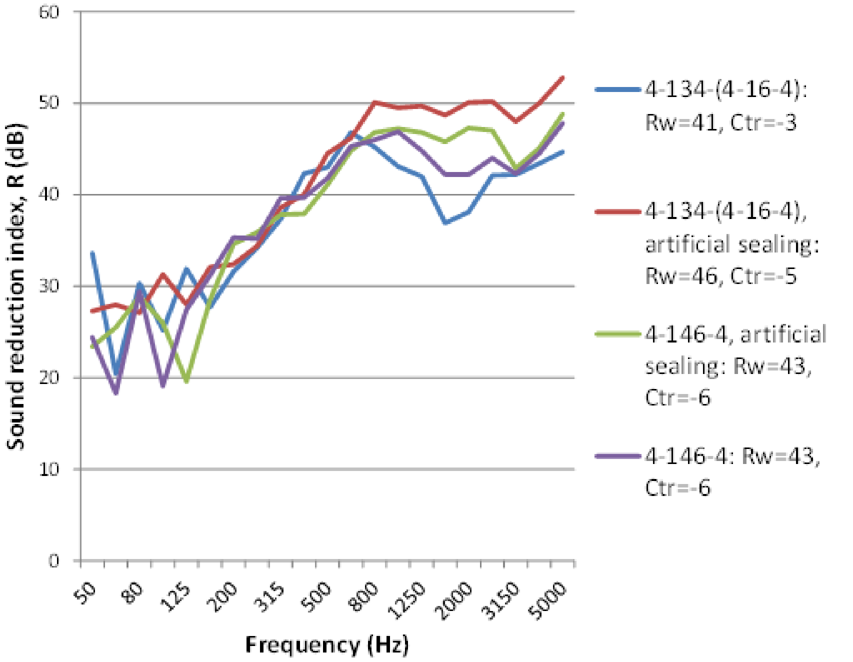


Figure 6.3
Sound reduction index for windows without and with artificial sealing

The measurement curves show that the sealing is of great significance for the sound reduction index at higher frequencies and some significance at low frequencies, i.e. in a frequency range determined by the dimensions of the gap. The measurement results indicate that sealing in connection with secondary casement has the strongest effect. Table 6.1 shows measured single number values for the different windows with and without artificial sealing.

Table 6.1
Measurement of double casement window without and with artificial sealing

Double casement window	Laboratory measurement of sound insulation, R_w (dB)		Laboratory measurement of sound insulation, $R_w + C_{tr}$ (dB)	
	Sealing strips as delivered	Artificial sealing	Sealing strips as delivered	Artificial sealing
Original window	28	30	25	26
Secondary casement with single glazing, 146 mm gap	43	43	37	37
Secondary casement with double glazing, 74 mm gap	39	41	33	33
Secondary casement with double glazing, 134 mm gap	41	46	38	41

The single number values in Table 6.1 show that optimal sealing in this case amounts to from 1 to 5 dB of the R_w value and from 0 to 3 dB of the value for $R_w + C_{tr}$. As expected, the table shows that the better the solution with respect to area weight and cavity depth, the more important is the sealing.

In practice it will not be realistic to achieve such an improvement with the aid of known sealing strips, but it will be possible to find solutions that result in somewhat better measurement values than the chosen sealing strips. The table also shows that the secondary casement with single glazing may provide better sound insulation than a secondary casement with double glazing when the area weight and cavity depths are moderate. Measured results for secondary casements with double glazing and a cavity depth of 134 mm are comparable with earlier measurement data, see SINTEF Byggforsk (2006).

6.3 Calculation and assessment of sound insulation

The sound reduction index for composite structures generally will for large parts of the frequency range be determined by the surface weight in combination with the cavity gaps, and it possible to calculate these indices with a high degree of accuracy. For the windows in this project, this frequency range is from 160 to approx. 630 Hz. In the frequency range higher than this, the sound reduction index is determined by the sealing, which it is difficult to calculate. In the low frequency range, the sound reduction index is largely determined by the cavity depths in combination with surface weight, sealing of the gap between casement and frame and connection via frame. Theoretical calculation shows that we should get an improvement of the sound reduction index of 2.5 dB when the secondary casement is moved from the outer to the inner position. This is because the cavity resonance is displaced 20-25 Hz towards lower frequencies. The measurements show approximately the same improvement in the frequency range 315-2000 Hz with an increase of 2 dB in the R_w value. It is possible to calculate the airborne sound insulation of the window when one replaces or optimises the glass in the secondary casement.

7. Heat balance

7.1 Radiation properties of glazings

Heat loss through the windows accounts for a substantial part of a building's overall heat loss. This amount can be especially large in small houses with old windows, but given upgrading with a secondary casement with a good glazing, the heat loss through old, culturally valuable windows can be as low as for new windows. More layers of glass do not just reduce the U-value; the glazing also let in less solar heat and somewhat less daylight. The total solar factor, g, indicates how large a proportion of solar energy comes through a glazing. The light transmission factor, LT, indicates how large a proportion of the visible light passes through the glazing. These values in addition to the U-value have a bearing on the heat balance of the windows and the energy requirements of a building.

The total solar transmission factor, g, and the light transmission factor, LT, for a number of possible pane combinations for a glazing are calculated with the program WINDOW 6 and shown in Table 7.1 together with the U-value of the middle portion of the glazing. The calculated U-values of a number of types and sizes of windows with the same glazing are shown in Chapter 8.

7.2 Calculated energy needs

In large buildings like office buildings there is a heat surplus for much of the year and reduced solar heat is usually desirable because it reduces the need for cooling. In dwellings, by contrast, solar heating can provide desirable additional energy, particularly in spring and autumn. To obtain a correct picture of how much energy can be saved by upgrading the windows with secondary casements with god glazing, account must also be taken of the fact that more layers of glass reduce desired additional solar heating.

We used SINTEF's "TEK-sjekk" program to calculate heat loss figures and energy requirements for a standard small house with three of the window varieties for which we have measured the U-value. The three variants are the window without a secondary casement, the window with a secondary casement with single glazing and the window with a secondary casement with double glazing, both in the middle position. The house has two storeys with a total of 160 m² of floor area and a window area of 32 m², which is 20% of the floor area. The window area consists of 10 m² facing south and north and 6 m² facing east and west. Floor, walls and ceiling and all installations have been upgraded to satisfy the requirements in TEK10.

The results of the calculations are shown in Table 7.2.

Table 7.1
The table gives the U-value of the middle portion of the glazing, total solar transmission and light transmission for various possible pane combinations.

Glazing structure	U-value of glazing U_G, W/m²K	Solar transmittance g	Light transmittance LT
4	5.75	0.85	0.90
4-74-4	2.76	0.75	0.81
4-74-E4	1.87	0.70	0.74
4-74-4-12-4	1.83	0.67	0.73
4-74-4-12-E4	1.22	0.53	0.72
4-74-4-12Ar-E4	1.02	0.53	0.72
4-74-4-12Kr-E4	0.85	0.53	0.72
4-74-E4-12-E4	0.98	0.52	0.66
4-74-E4-12Ar-E4	0.84	0.51	0.66
4-74-E4-12Kr-E4	0.69	0.50	0.66
4-74-4-16-4	1.78	0.66	0.73
4-74-4-16-E4	1.08	0.53	0.72
4-74-4-16Ar-E4	0.93	0.53	0.72
4-74-4-16Kr-E4	0.88	0.53	0.72
4-74-E4-16-E4	0.88	0.51	0.66
4-74-E4-16Ar-E4	0.76	0.50	0.66
4-74-E4-16Kr-E4	0.71	0.50	0.66

An explanation of the codes in the column Glazing structure is given in Chapter 3.

Table 7.2
Calculated heat loss coefficients and energy requirements for a standard detached house with three possible window and glazing structures.

Window and glazing structure	Heat loss coefficient W/m²K	Change %	Energy required for heating kWh/m²year	Change %	Total energy requirements kWh/m²year	Change %
Window with single glass, 4	1.49		121		187	
Window with secondary casement 1 4-74-E4	0.95	-36	66	-46	132	-29
Window with secondary casement 2 4-74-E4-16Ar-E4	0.83	-44	56	-53	122	-35

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8. Other window variants

8.1 Calculated U-values for other window variants

Tables 8.1, 8.2, 8.3 and 8.4 show calculated U-values for four types of window with various pane combinations and window sizes. We have used the exact method in the calculations, with frame-casement values calculated with the program THERM 6.3. The same frame-casement cross-section is used as the test window with secondary casements in the middle position; see section drawings and description in Chapter 3.

As the measurements showed, the U-value of the window was relatively independent of whether the secondary casement was in the middle or inner position. This is consistent with calculations of the U-value for the middle portion of the glazing, which shows that U_G is virtually constant for cavity depths of more than about 15 mm. The U-value tables can therefore be used with good approximation also for cavity depths other than the 74 mm used in the calculations.

Windows with frame-casement profiles with other dimensions will have slightly different U_F values from the test window. If the profiles are deeper, U_F will increase a little, but minor difference from the frame-casement sections that are used in the calculations will result in little change in the U-values for the whole window. The position of the secondary casement will affect both U_F and the linear thermal transmittance a little, but as the measurements and exact method calculations in Table 4.2 show, they will not affect the U-value of the whole window much. In our view, the U-value tables can therefore be used for the majority of ordinary casement profiles.

Explanation of pane codes used in Column 1 in the tables:
- The figures give the thickness in mm of glass and cavity measured from the outside.
- The letter E indicates that the glass has a low-emission coating (heat-reflecting coating).
- The letters Ar or Kr after the cavity thickness indicate that the cavity is filled with argon or krypton. Argon and krypton are inert gases that insulate better than air.
- In our calculations we have assumed that cavities containing inert gas are filled with 90% gas and the remainder air.
- When there are no letters after the cavity thickness, the cavity is filled with air.

In the U-value tables, the U-values are colour coded. The highest U-values have the reddest colour, and the lowest U-values have the greenest colour.

The outer casement is assumed to have a single layer of ordinary glass. Single-glazed casements have approximately the same insulating capacity irrespective of whether the casement has one large pane or is divided into smaller panes with through-going glazing bars. The U-value tables can therefore be used for all the pane arrangements in the outer casement that are shown in the figure above the table. When the secondary casement has a double glazing, it is assumed that there is just one large glazing in each casement, without through-going or intermediate glazing bars.

As the tables show, the calculated U-values for the four types of window are relatively similar when they have the same glazing. The U-values are also relatively independent of the size of the window.
When the U-value of the frame and casement, U_F, is approximately the same as the U-value of the middle portion of the glazing, U_G, the U-value of the window, U_W, is roughly the same for all window sizes.
With poor glazing, U_G will be higher than U_F and the U-value of the window will increase with increasing window size. This is because the glazing accounts for an increasing proportion of the window area when the size of the window increases. With good glazings with low U_G the opposite will apply. The window's U-value will then fall somewhat with increasing window size.

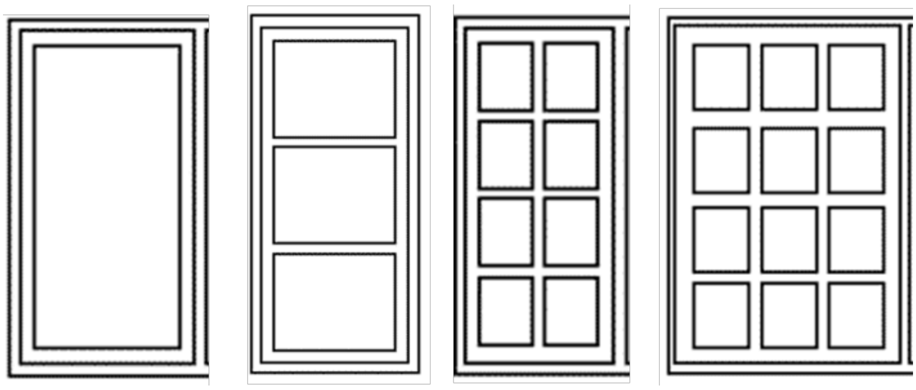

Figure 8.1
Single casement windows. From BKS 733.161 Eldre vinduer. Vindusformer og materialer. [Old windows. Window shapes and materials].

Table 8.1
U-values of single casement windows, post-insulated with single or double glazing in internal secondary casement. The U-values are colour coded. The highest U-values have the reddest colour, and the lowest U-values have the greenest colour. The U-values in the table apply to all types of window shown in Fig. 8.1.

Witdh of window frame, m			0.6	0.6	0.6	0.8	0.8	0.8	1.0	1.0	1.0
Height of window frame, m			1.2	1.5	1.8	1.2	1.5	1.8	1.2	1.5	1.8
	U_g	U_F		U_W, U-value of complete window							
Glazing structure	W/m²K	W/m²K				W/m²K					
4	5.75	2.27	4.35	4.43	4.47	4.57	4.65	4.71	4.70	4.79	4.85
4-74-4	2.76	1.08	2.08	2.11	2.14	2.19	2.23	2.25	2.25	2.29	2.32
4-74-E4	1.87	1.08	1.56	1.57	1.59	1.61	1.63	1.64	1.64	1.66	1.67
4-74-4-12-4	1.83	0.97	1.57	1.58	1.59	1.61	1.62	1.64	1.63	1.65	1.66
4-74-4-12-E4	1.22	0.97	1.20	1.21	1.21	1.21	1.21	1.21	1.21	1.21	1.21
4-74-4-12Ar-E4	1.02	0.97	1.09	1.09	1.09	1.08	1.08	1.07	1.07	1.07	1.07
4-74-4-12Kr-E4	0.85	0.97	0.99	0.98	0.98	0.97	0.96	0.95	0.95	0.94	0.94
4-74-E4-12-E4	0.98	0.97	1.06	1.06	1.06	1.05	1.05	1.05	1.05	1.04	1.04
4-74-E4-12Ar-E4	0.84	0.97	0.98	0.98	0.97	0.96	0.96	0.95	0.95	0.94	0.94
4-74-E4-12Kr-E4	0.69	0.97	0.90	0.89	0.88	0.87	0.86	0.85	0.85	0.84	0.83
4-74-4-16-4	1.78	0.97	1.55	1.56	1.57	1.58	1.60	1.61	1.61	1.62	1.63
4-74-4-16-E4	1.08	0.97	1.14	1.14	1.14	1.13	1.13	1.13	1.13	1.12	1.12
4-74-4-16Ar-E4	0.93	0.97	1.05	1.04	1.04	1.03	1.02	1.02	1.02	1.01	1.01
4-74-4-16Kr-E4	0.88	0.97	1.02	1.01	1.01	1.00	0.99	0.98	0.98	0.98	0.97
4-74-E4-16-E4	0.88	0.97	1.02	1.01	1.01	1.00	0.99	0.99	0.98	0.98	0.97
4-74-E4-16Ar-E4	0.76	0.97	0.95	0.94	0.94	0.92	0.91	0.91	0.90	0.89	0.89
4-74-E4-16Kr-E4	0.71	0.97	0.92	0.91	0.91	0.89	0.88	0.87	0.87	0.86	0.85

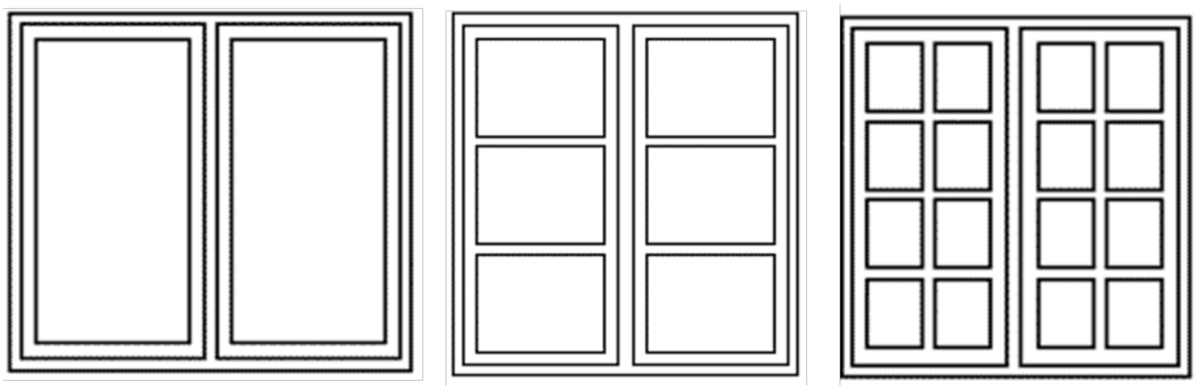

Figure 8.2
Double casement windows with central mullion. From BKS 733.161 Eldre vinduer. Vindusformer og materialer. [Old windows. Window shapes and materials].

Table 8.2
The table gives U-values of double casement windows. Windows with mullion and single glass in outer casements secondarily insulated with single- or double-glazing in internal secondary casements.
The U-values are colour coded. The highest U-values have the reddest colour, and the lowest U-values have the greenest colour. The U-values in the table apply to all types of window shown in Fig. 8.2.

Witdh of window frame, m			1.0	1.0	1.0	1.2	1.2	1.2	1.4	1.4	1.4
Height of window frame, m			1.2	1.5	1.8	1.2	1.5	1.8	1.2	1.5	1.8
	U_g	U_F	U_W, U-value of complete window								
Glazing structure	W/m²K	W/m²K	W/m²K								
4	5.75	2.42	4.41	4.48	4.53	4.55	4.63	4.68	4.64	4.73	4.78
4-74-4	2.76	1.11	2.10	2.14	2.16	2.17	2.21	2.24	2.22	2.26	2.29
4-74-E4	1.87	1.11	1.58	1.60	1.61	1.61	1.63	1.64	1.63	1.65	1.66
4-74-4-12-4	1.83	0.95	1.54	1.56	1.57	1.58	1.59	1.60	1.60	1.61	1.63
4-74-4-12-E4	1.22	0.95	1.18	1.19	1.19	1.19	1.19	1.19	1.19	1.19	1.19
4-74-4-12Ar-E4	1.02	0.95	1.07	1.07	1.07	1.07	1.06	1.06	1.06	1.06	1.06
4-74-4-12Kr-E4	0.85	0.95	0.97	0.96	0.96	0.96	0.95	0.94	0.95	0.94	0.94
4-74-E4-12-E4	0.98	0.95	1.05	1.04	1.04	1.04	1.04	1.03	1.04	1.03	1.03
4-74-E4-12Ar-E4	0.84	0.95	0.97	0.96	0.95	0.95	0.95	0.94	0.95	0.94	0.93
4-74-E4-12Kr-E4	0.69	0.95	0.88	0.87	0.86	0.86	0.85	0.84	0.85	0.84	0.83
4-74-4-16-4	1.78	0.95	1.52	1.54	1.55	1.55	1.57	1.58	1.57	1.59	1.60
4-74-4-16-E4	1.08	0.95	1.12	1.12	1.12	1.12	1.11	1.11	1.12	1.11	1.11
4-74-4-16Ar-E4	0.93	0.95	1.03	1.02	1.02	1.02	1.01	1.01	1.01	1.01	1.00
4-74-4-16Kr-E4	0.88	0.95	1.00	0.99	0.99	0.99	0.98	0.98	0.98	0.97	0.97
4-74-E4-16-E4	0.88	0.95	1.00	0.99	0.99	0.99	0.98	0.98	0.98	0.97	0.97
4-74-E4-16Ar-E4	0.76	0.95	0.93	0.92	0.92	0.91	0.90	0.90	0.90	0.89	0.89
4-74-E4-16Kr-E4	0.71	0.95	0.90	0.89	0.89	0.88	0.87	0.87	0.87	0.86	0.85

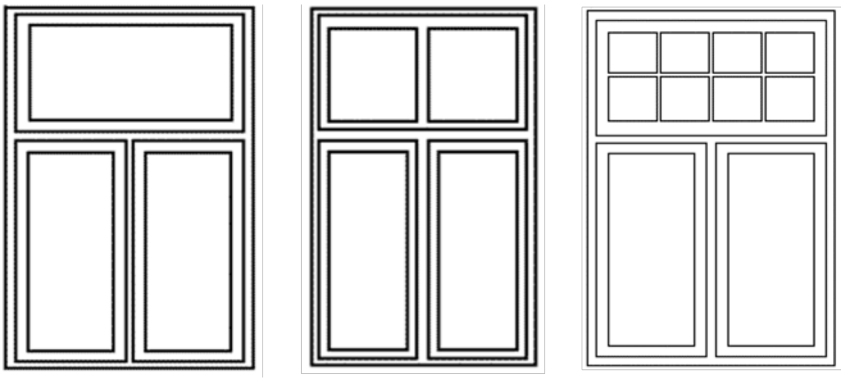

Figure 8.3
Triple casement windows (T-mullioned windows) From BKS 733.161 Eldre vinduer. Vindusformer og materialer. [Old windows. Window shapes and materials].

Table 8.3
The table gives U-values of triple casement windows. T-mullioned windows, with single glass in outer casements, secondarily insulated with single- or double glazing in internal secondary casements.
The U-values are colour coded. The highest U-values have the reddest colour, and the lowest U-values have the greenest colour. The U-values in the table apply to all types of window shown in Fig. 8.3.

Witdh of window frame, m			1.0	1.0	1.0	1.2	1.2	1.2	1.4	1.4	1.4
Height of window frame, m			1.2	1.5	1.8	1.2	1.5	1.8	1.2	1.5	1.8
	U_g	U_F	U_W, U-value of complete window								
Glazing structure	W/m²K	W/m²K	W/m²K								
4	5.75	2.47	4.03	4.14	4.21	4.21	4.33	4.41	4.33	4.46	4.54
4-74-4	2.76	1.13	1.92	1.97	2.00	2.00	2.06	2.10	2.06	2.13	2.17
4-74-E4	1.87	1.13	1.51	1.53	1.55	1.55	1.57	1.59	1.57	1.60	1.62
4-74-4-12-4	1.83	0.94	1.44	1.47	1.49	1.48	1.51	1.53	1.51	1.54	1.56
4-74-4-12-E4	1.22	0.94	1.16	1.17	1.17	1.17	1.17	1.18	1.17	1.18	1.18
4-74-4-12Ar-E4	1.02	0.94	1.07	1.07	1.07	1.07	1.06	1.06	1.06	1.06	1.06
4-74-4-12Kr-E4	0.85	0.94	0.99	0.98	0.98	0.98	0.97	0.96	0.97	0.96	0.95
4-74-E4-12-E4	0.98	0.94	1.05	1.05	1.05	1.04	1.04	1.04	1.04	1.04	1.03
4-74-E4-12Ar-E4	0.84	0.94	0.99	0.98	0.98	0.97	0.97	0.96	0.96	0.96	0.95
4-74-E4-12Kr-E4	0.69	0.94	0.92	0.91	0.90	0.90	0.88	0.87	0.88	0.87	0.86
4-74-4-16-4	1.78	0.94	1.43	1.46	1.47	1.47	1.50	1.51	1.49	1.52	1.54
4-74-4-16-E4	1.08	0.94	1.11	1.11	1.12	1.11	1.11	1.11	1.11	1.11	1.11
4-74-4-16Ar-E4	0.93	0.94	1.04	1.04	1.04	1.03	1.03	1.02	1.02	1.02	1.01
4-74-4-16Kr-E4	0.88	0.94	1.02	1.01	1.01	1.00	1.00	0.99	1.00	0.99	0.98
4-74-E4-16-E4	0.88	0.94	1.02	1.01	1.01	1.01	1.00	0.99	1.00	0.99	0.98
4-74-E4-16Ar-E4	0.76	0.94	0.96	0.96	0.95	0.95	0.93	0.93	0.93	0.92	0.91
4-74-E4-16Kr-E4	0.71	0.94	0.94	0.93	0.92	0.92	0.91	0.90	0.91	0.89	0.88

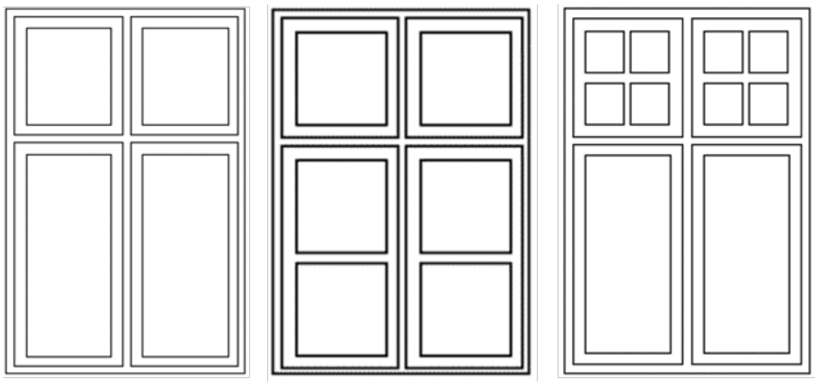

Figure 8.4
Quadruple casement windows (cross-mullioned windows) From BKS 733.161 Eldre vinduer. Vindusformer og materialer. [Old windows. Window shapes and materials].

Table 8.4
The table gives U-values of Quadruple casement windows. Cross-mullioned windows, with single glass in outer casements, secondarily insulated with single- or double glazing in internal secondary casements.
The U-values are colour coded. The highest U-values have the reddest colour, and the lowest U-values have the greenest colour. The U-values in the table apply to all types of window shown in Fig. 8.4.

Witdh of window frame, m			1.0	1.0	1.0	1.2	1.2	1.2	1.4	1.4	1.4
Height of window frame, m			1.2	1.5	1.8	1.2	1.5	1.8	1.2	1.5	1.8
	U_g	U_F	U_W, U-value of complete window								
Glazing structure	W/m²K	W/m²K	W/m²K								
4	5.75	2.48	4.21	4.32	4.40	4.33	4.45	4.53	4.42	4.54	4.63
4-74-4	2.76	1.13	2.00	2.06	2.09	2.06	2.12	2.16	2.10	2.17	2.21
4-74-E4	1.87	1.13	1.54	1.57	1.59	1.57	1.60	1.62	1.59	1.62	1.64
4-74-4-12-4	1.83	0.94	1.48	1.51	1.52	1.51	1.54	1.56	1.53	1.56	1.58
4-74-4-12-E4	1.22	0.94	1.16	1.17	1.17	1.17	1.17	1.18	1.17	1.18	1.18
4-74-4-12Ar-E4	1.02	0.94	1.06	1.06	1.06	1.06	1.06	1.06	1.06	1.06	1.06
4-74-4-12Kr-E4	0.85	0.94	0.97	0.97	0.96	0.96	0.96	0.95	0.96	0.95	0.94
4-74-E4-12-E4	0.98	0.94	1.04	1.04	1.04	1.04	1.04	1.03	1.04	1.03	1.03
4-74-E4-12Ar-E4	0.84	0.94	0.97	0.96	0.96	0.96	0.95	0.95	0.96	0.95	0.94
4-74-E4-12Kr-E4	0.69	0.94	0.90	0.88	0.87	0.88	0.87	0.86	0.87	0.86	0.84
4-74-4-16-4	1.78	0.94	1.46	1.49	1.51	1.49	1.52	1.53	1.51	1.54	1.55
4-74-4-16-E4	1.08	0.94	1.11	1.11	1.11	1.11	1.11	1.11	1.11	1.11	1.11
4-74-4-16Ar-E4	0.93	0.94	1.03	1.02	1.02	1.02	1.02	1.01	1.02	1.01	1.01
4-74-4-16Kr-E4	0.88	0.94	1.00	1.00	0.99	0.99	0.99	0.98	0.99	0.98	0.97
4-74-E4-16-E4	0.88	0.94	1.00	1.00	0.99	1.00	0.99	0.98	0.99	0.98	0.97
4-74-E4-16Ar-E4	0.76	0.94	0.94	0.93	0.93	0.93	0.92	0.91	0.92	0.91	0.90
4-74-E4-16Kr-E4	0.71	0.94	0.92	0.91	0.90	0.90	0.89	0.88	0.89	0.88	0.87

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10. Appendix – measuring methods

10.1 Measuring U-values by use of hot box

The measurements are carried out according to NS-EN ISO 12567 (2010) which is an international standard for measuring the U-value of windows and doors by use of a hot box.

During measurement in SINTEF Byggforsk's hot box, the window is mounted into an opening in a surround panel. The width of the opening is 1.24 m and the height is 1.24 m or 1.50 m. The space between the window and the surround panel is filled with EPS with known thermal conductivity.

The metering area of the measurement chamber is 2.45 m x 2.45 m, and the window is placed as in a normal wall with a distance of 0.2 m from the ceiling and down to the top of the frame. A correction is made for the heat flow through the surround panel area around the window. Measurement takes place under stationary conditions with ambient temperatures close to 20°C and 0°C on the warm and cold side, respectively, of the window.
The U-value of the window is calculated on the basis of the measured heat flow, ambient temperatures and area of the window, and is based on average values for several one-hour measurement periods. During the measurement, the surface resistances may vary a little from the standardized values, and the barometer pressure may differ somewhat from normal pressure, but corrections are made for both these factors. The specified, standardized U-value therefore applies to an overall, standardized surface resistance of 0.17 m^2K/W and at normal atmospheric pressure.

Figure 10.1
The picture shows SINTEF Byggforsk's hot box during installation of the surround panel with the window. The window is installed in a surrond panel that is set in as a divider between a warm room on the left and a cold room that is concealed behind the surround panel.

10.2 Measuring air flow

The leakage of air through the window and alternative holes for airing were measured at four different air pressure differences. In order to measure air passage, an airtight box was fitted to the outside of the window. Pipes to supply air and to measure the difference in air pressure between the two sides of the window were fitted to the box. The air flow was measured by means of rotameters and the pressure difference was measured with a micromanometer.

Figure 10.2
The picture shows the set-up of the test for measuring air leakage. The window on the right with the airtight box behind it and the rotameters for measuring air passage on the left. On the far left is the micromanometer for measuring the air pressure difference between the external and internal surfaces of the window.

10.3 Measuring airborne sound insulation

Description of sound laboratory
SINTEF Byggforsk's sound laboratory, room U48-49, was modified in spring 2005/autumn 2008 to satisfy all the requirements for measuring doors and windows according to NS-EN ISO 140 (2005). Plan and cross-section drawings of the laboratories are given below.

The laboratory consists of a transmitter room with a volume of about 70 m³ and a receiver room with a volume of approximately 80 m³ which is structurally quite separate, with a throughgoing joint between the rooms of 20 mm. The test opening between the transmitter room and receiver room (sound room), originally 10 m², has been blocked with double walls of 200 mm concrete with 20 mm mineral wool in the joint between the member walls. Two openings have been made in this wall, one for testing windows and one for testing doors. Both openings can be closed with steel doors on both sides for alternate testing of doors and windows. The total thickness of the blocking wall is 420 mm. The test opening for windows is width 1250 mm, height 1500 mm on the sound room side, and width 1370 mm, height 1560 on the transmitter room side (see below regarding requirements for niche design). The test opening for doors is width 1250 mm x height 2250 mm on the sound room side and width 1370 mm x height 2310 mm on the transmitter room side. The test opening for doors extends almost right down to the floor for the transmitter and receiver room which is recommended for door testing. The test opening for installing doors is further blocked down from this, depending on the width and height of the actual test door.

Accredited testing
SINTEF Byggforsk's laboratory for sound insulation measurement and step sound insulation is accredited. An accreditation is a third party's assessment of qualification for performing specific tasks. This means that we satisfy all the requirements of NS-EN ISO/IEC 17025 and are audited annually by Norsk Akkreditering (NA). For further information, see NA's website. (www.akkreditert.no)

Traceability

Measuring instrument	Type	Series no.
Analyser	Norsonic 121	28720
Microphone	Norsonic 1220	32559
Microphone	Norsonic 1220	35058
Microphone preamplifier	Norsonic 1201	18085
Microphone preamplifier	Norsonic 1201	30519
Calibrator	Norsonic 1251	622326
Loudspeaker	Norsonic	21701
Loudspeaker amplifier	Norsonic	22652

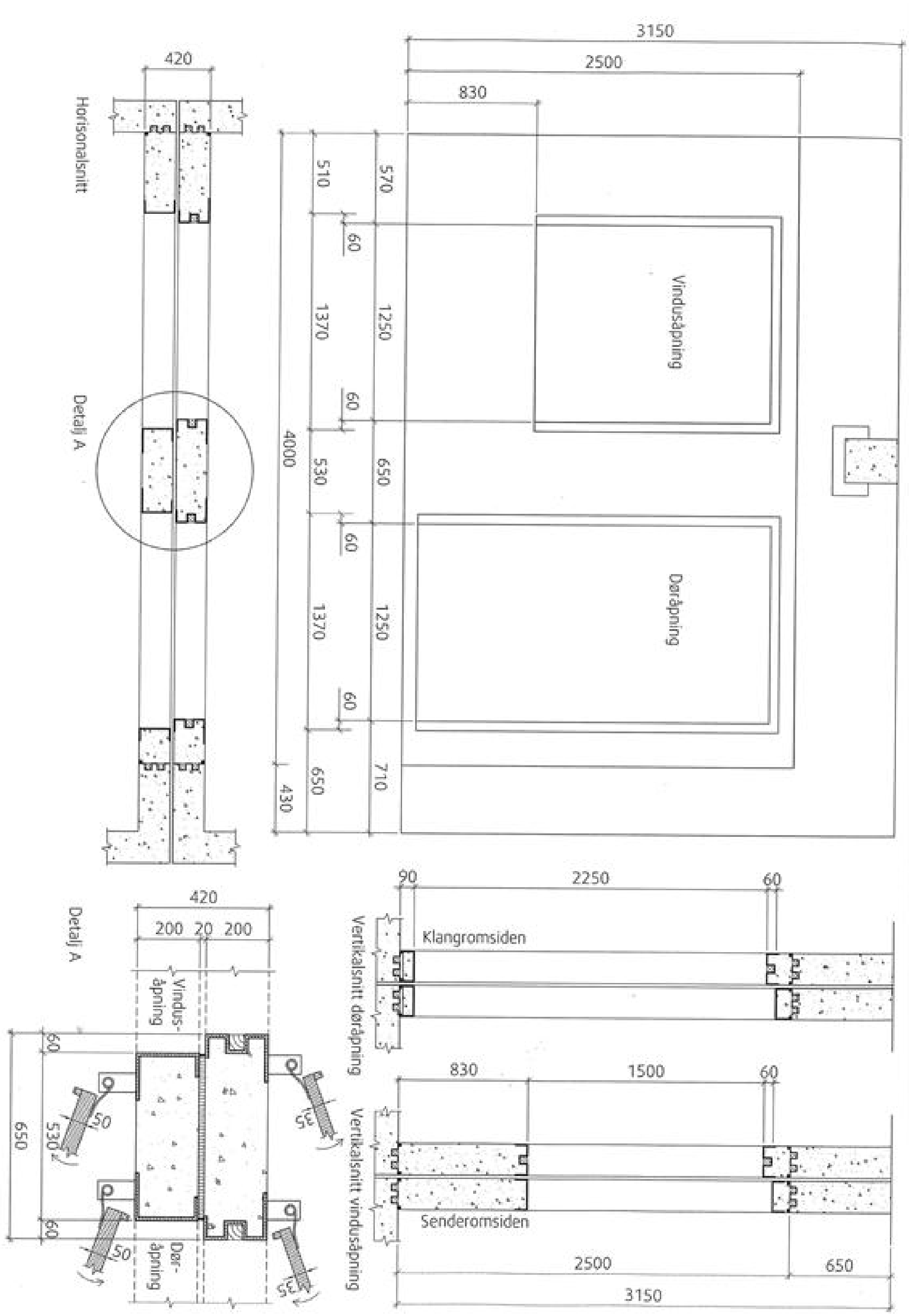


Figure 10.3
Plan and cross-section drawings of the laboratories

11. Appendix – calculation methods

11.1 Calculation of U-value, exact method

A window consists of frame, casement and glazing. These components have different thermal insulation properties, depending on material properties, structure and geometry. Heat losses through frame and casement are strongly interdependent and the U-value of frame and casement is therefore given a common U-value, $U_{F.}$. The heat loss through a glazing is lowest in the middle portion of the glazing and the U-value of this area is called $U_{G.}$ The heat loss is somewhat greater in an edge zone of about 100 mm from the light opening, and increases with declining distance from the edge of the glazing, where heat loss is greatest. This extra heat loss in the edge zone is due to the fact that the spacer between the panes insulates more poorly than the cavity, and is designate linear thermal transmittance. The linear thermal transmittance, Ψ_F, is defined as heat loss per running meter of glazing edge, W/mK.

In order to obtain the most correctly calculated U-value, the U-value of the frame and casement profiles, U_{KR}, and the linear thermal transmittance, Ψ_F, must be calculated according to NS-EN ISO 10077-2 by use of a computer program for two-dimensional heat flow. We used the THERM 6.3 modeling program.
The U-value of the glazing, U_G, is calculated according to ISO 15099 (2003) and the resulting values agree well with the measured values.

The overall U-value for the whole window, U_W, is calculated as the area-weighted average value for the whole window area on the basis of the U-value and areas of the frame/casement and glazing plus the linear thermal transmittance and total length of the edge of the glazings pursuant to NS-EN ISO 10077-1 (2006).

11.2 Calculation of U-value, simplified method

Simplified calculation takes place according to the same principles as exact calculation, but the U-value of frame and casement, U_F, and the linear thermal transmittance, Ψ_F, are calculated in a simplified manner according to the rules in NS-EN ISO 10077-1 (2006). Here too, the U-value for the Glazing, U_G, is calculated according to ISO 15099 (2003).

11.3 Calculating heat balance

Heat loss figures and energy needs for a standard detached house are calculated using the SINTEF Byggforsk program "TEK-sjekk". The program calculates the heat balance of the building from hour to hour throughout a whole year according to NS 3031:2007.

12. Appendix – measurement results

12.1 Temperature profiles

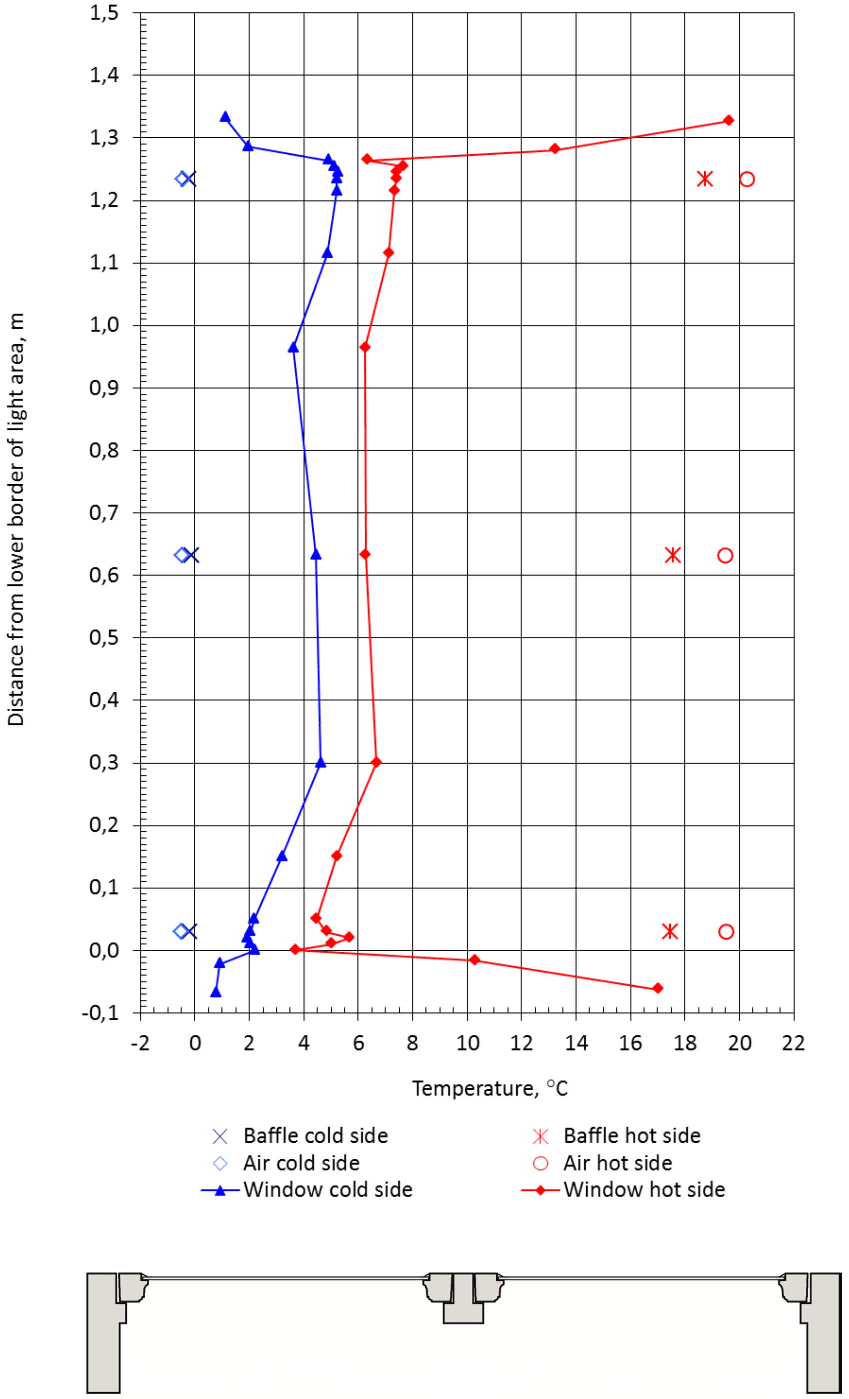
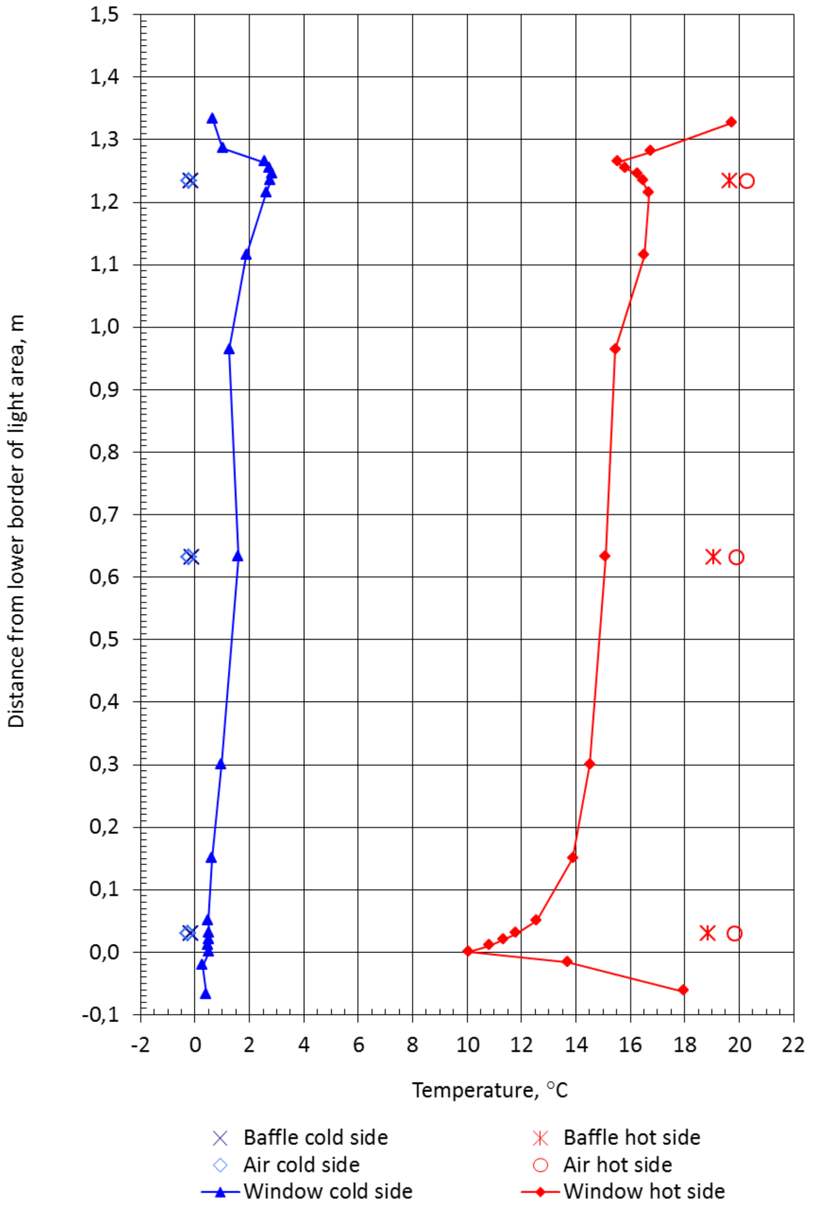


Figure 12.1
The diagram shows measured temperatures on the cold and the warm side of the window with only outer casements and single glass. The points connected with lines shows temperatures measured on the surface of the window along the vertical mid-line of the panes. The two uppermost and the two lowermost values were measured in the middle of the frame and casement profiles, while the others were measured on the glass.



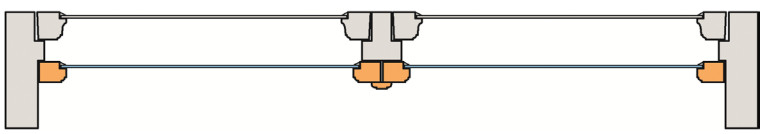
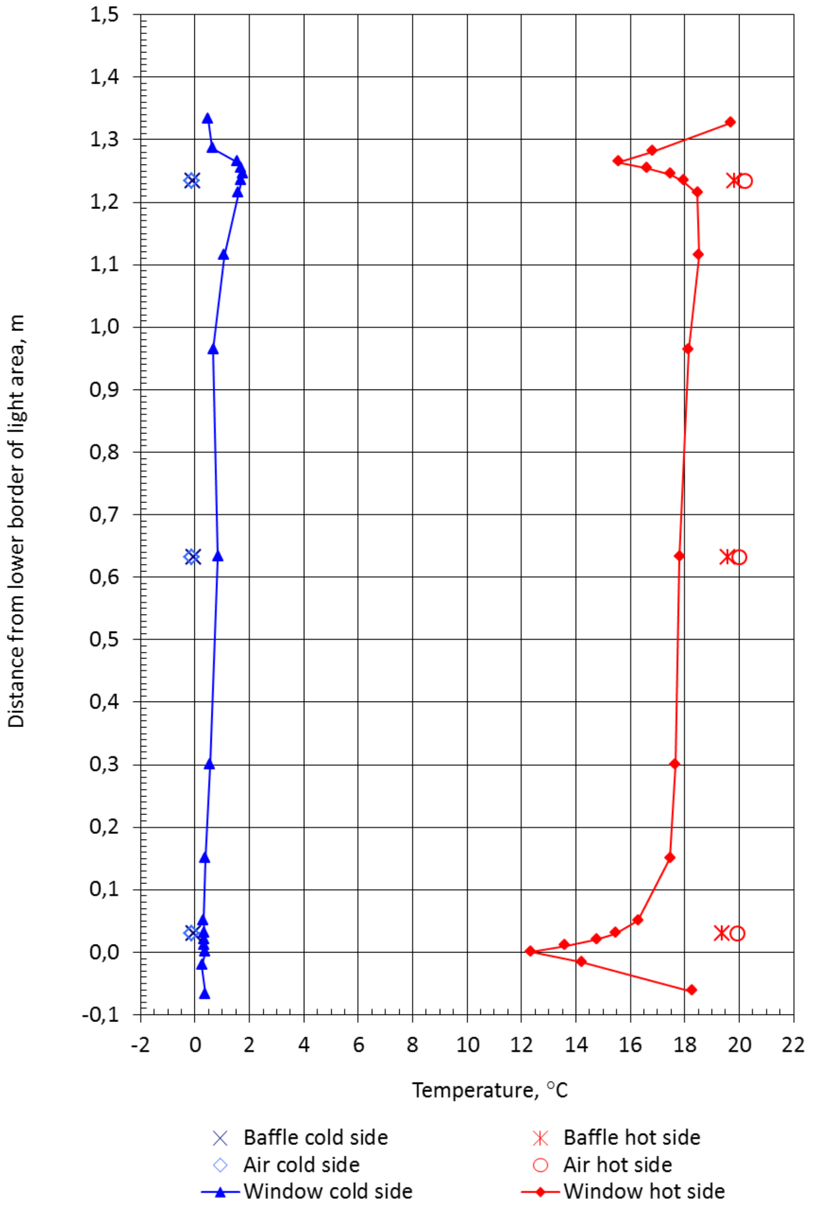


Figure 12.2
The diagram shows measured temperatures on the cold and warm sides of the window with single-glazed secondary casement in mid-position. Glazing code: 4-74-E4. The points connected with lines shows temperatures measured on the surface of the window along the vertical mid-line of one glazing. The two uppermost and the two lowermost values were measured in the middle of the frame and casement profiles, while the others were measured on the glazing.



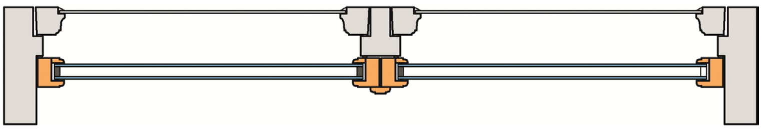


Figure 12.3
The diagram shows measured temperatures on the cold and warm sides of the window with double-glazed secondary casement in mid-position. Glazing code: 4-74-E4-16Ar-E4. The points connected with lines shows temperatures measured on the surface of the window along the vertical mid-line of one glazing. The two uppermost and the two lowermost values were measured in the middle of the frame and casement profiles, while the others were measured on the glazing.

12.2 Air flow

Results from measurements of air leakage through the window without extra casements, without holes for airing					
Pressure difference	12	23	53	105	Pa
Leakage, entire window	0,3	0,5	0,8	1,2	m^3/h
Leakage per window area	0,19	0,28	0,49	0,75	m^3/m^2 h

Results from measurements of air leakage through the window with extra casements, without holes for airing					
Pressure difference	12	19	50	103	Pa
Leakage, entire window	0,2	0,3	0,5	0,7	m^3/h
Leakage per window area	0,11	0,15	0,28	0,43	m^3/m^2 h

Results from measurements of air leakage through the window with 4 circular holes for airing, diameter Ø 4,6 mm, in the external casement					
Pressure difference	14	21	54	96	Pa
Leakage, entire window	0,7	0,9	1,5	2,2	m^3/h
Leakage per window area	0,44	0,56	0,89	1,36	m^3/m^2 h

Results from measurement of air flow through 4 circular holes for airing in the external casement								
Description of holes for airing			Pressure difference and air flow					
Number of holes per casement	Diameter	Hole area	It is corrected for air leaks through the window without holes for airing					
	mm	mm^2						
			Pressure difference	11	26	52	102	Pa
			Airflow per casement	0,2	0,3	0,5	0,6	m^3/h
2	4,6	33	Airflow per hole area	7	8	15	20	l/mm^2 h

Results from measurement of air flow through 4 rectangular holes for airing in the external casement									
Description of holes for airing				Pressure difference and air flow					
Number of holes per casement	With	Length	Hole area	It is corrected for air leaks through the window without holes for airing					
	mm	mm	mm²						
				Pressure difference	19	26	52	102	Pa
				Airflow per casement	0,8	1,0	1,5	2,2	m^3/h
4	2	10	80	Airflow per hole area	10	12	19	27	l/mm² h
				Pressure difference	14	24	46	90	Pa
				Airflow per casement	2,8	4,0	5,5	7,8	m^3/h
4	2	20	160	Airflow per hole area	18	25	35	49	l/mm² h
				Pressure difference	8	19	42	65	Pa
				Airflow per casement	3,0	5,0	7,7	9,6	m^3/h
4	2	30	240	Airflow per hole area	12	21	32	40	l/mm² h
				Pressure difference	9	17	41	46	Pa
				Airflow per casement	4,0	6,0	9,3	9,7	m^3/h
4	2	40	320	Airflow per hole area	12	19	29	30	l/mm² h
				Pressure difference	8	20	34		Pa
				Airflow per casement	4,7	7,6	9,7		m^3/h
4	2	50	400	Airflow per hole area	12	19	24		l/mm² h

12.3 *Sound reduction index*

Results of sound reduction measurements in the laboratory; see 10.3.

Solu-tion	**Single glass**		**Additional casement with single glass**		**Additional casement with double glazing**			**Additional casement with double glazing**	
	4		**4-146-4**		**4-74-(4-16-4)**			**4-134-(4-16-4)**	
Freq-uency	Sealing as delivered	Artificial sealing	Sealing as delivered	Artifi-cial sealing	Sealing as delivered	Artificial sealing	Corner open-ings	Sealing as delivered	Artificial sealing
50	10,1	17,1	24,4	23,4	31,6	30,8	28,1	33,6	27,3
63	15,2	10,3	18,3	25,5	22,8	25,8	26,2	20,4	28
80	21,3	21	29,4	28,9	29	28,7	27,5	30,3	27,1
100	13,3	16,5	19,1	26	15,8	16,5	14,2	25,2	31,3
125	16,7	13,8	27,4	19,6	19,8	17,6	17,7	31,9	28
160	19,1	17,1	31,2	28,5	29,9	27	24,7	27,7	32,1
200	18,8	19,9	35,3	34,6	33,1	32,1	31	31,6	32,4
250	16,8	21,8	35,2	35,9	30	30,2	28,3	34,2	34,4
315	24,5	26,1	39,6	37,8	35,4	36,4	32,2	37,3	38,6
400	26	25,7	39,7	37,9	38,6	39,6	37,8	42,3	40
500	26,7	26,6	41,8	41,1	40	41,6	38,8	43	44,5
630	27	27,2	45,3	44,8	45,1	46,4	43,4	46,8	46,2
800	28,9	29,3	46	46,8	43,5	46,7	42,2	45,2	50,1
1000	30,2	30,7	46,9	47,2	41,7	43,8	41	43,1	49,5
1250	30	31,3	44,8	46,8	39	45	38,4	42	49,7
1600	28,9	30,4	42,2	45,8	33,7	44,2	33,6	36,9	48,7
2000	29,6	31,3	42,2	47,3	36,3	43,1	34,8	38,1	50,1
2500	30,9	32,1	44	47	41,8	42,7	39,8	42,1	50,2
3150	29	30,1	42,3	42,9	42,2	42,3	41,1	42,2	48
4000	27,6	27,7	44,5	45,1	43,2	42,8	41,7	43,4	50
5000	27,8	28	47,8	48,8	44,8	44,7	43,2	44,7	52,8
R_w (dB)	28	30	43	43	39	41	37	41	46
R_w+C_{tr} (dB)	25	26	37	37	33	33	31	38	41

Enova intends to be the driving force behind an environmentally friendly restructuring of energy consumption and production in Norway.
Our task is to create permanent changes in the supply of and demand for efficient renewable energy systems.
Our aim is to provide inspiration that will make it simpler to choose forward-looking energy systems for both private and professional players.

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