BYG·DTU

# Designguide til valg af vinduesløsninger i boliger

Slutrapport til
BOLIGFONDENKUBEN

DANMARKS
TEKNISKE
UNIVERSITET

DTU

**Rapport R-192**
**isbn=9788778772688**
**BYG·DTU**
**June 2008**

# Designguide til valg af vinduesløsninger i boliger

## Slutrapport til BoligfondenKuben

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# Forord

Nærværende rapport er slutrapport for projektet med titlen *Designguide til valg af vinduesløsninger i boliger* støttet af BoligfondenKuben. Projektet er udført i perioden august 2007 til juni 2008 på BYG·DTU, Danmarks Tekniske Universitet.

Målet med projektet var at udvikle et værktøj til optimering af energirigtig valg af vinduer til boliger i Danmark. Værktøjet kan både anvendes til nybyggeri og ved renovering af det eksisterende byggeri samt til almindelige huse eller lejligheder.

Værktøjet er vedlagt denne rapport på CD og kan desuden downloades fra www.byg.dtu.dk

Projektgruppen vil gerne takke BoligfondenKuben for at have støttet projektet med udarbejdelsen af dette værktøj, der frit kan anvendes af alle og desuden vil blive inddraget i undervisningen på Danmarks Tekniske Universitet i forbindelse med kurser om energirigtigt byggeri. Da undervisningen i de relevante kurser foregår på både dansk og engelsk er programmet lavet med kombineret dansk og engelsk brugerflade og dokumentationsafsnittet i denne rapport er på engelsk.

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**BILAG 1**

Paper, Tool for selection of windows in dwellings

8TH Nordic Symposium Building Physics

**BILAG 2**

Præsentation, Tool for selection of windows in dwellings

8TH Nordic Symposium Building Physics

# Resumé

I dette projekt er udviklet et værktøj, der kan hjælpe arkitekter og ingeniører til at vælge den optimale vinduesløsning til boliger. Værktøjet kan bruges i design fasen til nybyggeri eller ved renovering af eksisterende boliger.

Værktøjet, der er udviklet I Microsoft Office Excel 2007 og Visual Basic for Applications (VBA), er opbygget som et brugervenligt regneark baseret på simple input til beregningen. Værktøjet er både anvendeligt for den erfarne og uerfarne bruger mht. til vinduesvalg. For eksempel kan den uerfarne bruger anvende prædefinerede standard vinduesløsninger, mens den mere erfarne bruger kan udnytte værktøjets fleksibilitet til selv at opbygge vinduesløsninger.

Værktøjet anvender fire STEPs til udvælgelsen af de bedste vinduer til boligen. De fire step benævnes i værktøjet STEP 1, STEP 2, STEP 3 og STEP 4

I STEP 1 kan brugeren opbygge, analysere og sammenligne forskellige individuelle vinduers energimæssige ydeevne bestemt ud fra kendskab til geometri og komponenter (rude og ramme/karm mm.). Denne første vurdering er baseret på vinduers energitilskud (Energitilskudsligningen), som beskrevet i Nielsen T. R. et. al. (2001).

I STEP 2 kan brugeren anvende de vinduer, der blev opbygget i STEP 1 til en specifik bolig. For hvert vindue må brugeren angive orientering, horisontafskærmning, udhæng, og evt. sidefinner samt solafskærmning. Brugeren kan opbygge flere forskellige scenarier for forskellige vinduesvalg til boligen. Afhængigt af fleksibiliteten i designfasen, så kan scenarierne være forskellige mht., vindueskomponenter, vinduesgeometri og vinduesorientering. Ved en sæsonbaseret (sommer/vinter) beregning for hvert vinduesscenarie, bestemmes dels vinduernes energiforbrug separat og dels boligens energiforbrug totalt mht. opvarmning og køling. Beregningen tager højde for udnyttelsesfaktoren for hhv. varme og køling jf. CEN(2008, ISO 13790).

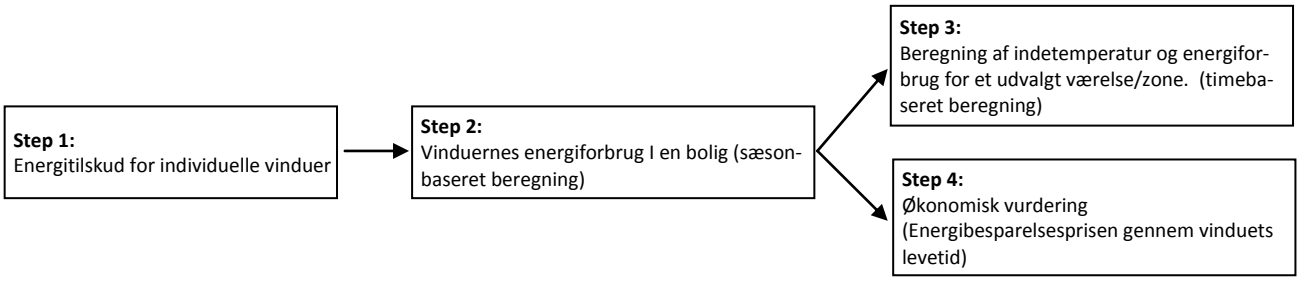
I STEP 3 foretages en beregning efter “the simple hourly method” beskrevet i CEN(2008, ISO 13790). For et rum eller en zone i boligen foretages en timebaseret beregning af energiforbrug (varme/kølebehov) og indetemperatur. Hovedformålet er at kontrollere hvordan de forskellige vinduesscenarier opfylder kravene til indeklima jf. standarden CEN( 2007, EN 15251).

I STEP 4 foretages en økonomisk vurdering af de forskellige vinduesscenarier, der er opbygget i STEP 1 og 2. Ved at vælge et referencescenarie er det muligt at beregne ”Energibesparelsesprisen” til en økonomisk vurdering af hvert scenarie.

Med analyserne foretaget under de fire STEPs kan brugeren foretage et optimeret valg af den bedste energimæssige vinduesløsning til en bolig.

Brugeren skal ikke nødvendigvis anvende alle fire STEPs. Brugeren kan nøjes med at anvende STEP 1 til et hurtigt overblik over forskellige vinduers energimæssige ydeevne mht. geometri og komponenter. Ligeledes kan brugeren nøjes med at anvende STEP 2 til en sæsonbaseret energiberegning for en bolig, såfremt der haves data for vinduernes U-værdi og g-værdi. STEP 3 og STEP 4 er uafhængige, men kræver at STEP 2 er gennemført.

På Figur 1 ses en skitse, der giver en overblik over værktøjets fire STEPS’s.




*Figur 1 - Skitse med overblik over de forskellige STEP I beregningsværktøjet*

# Summary

The tool presented was developed with the purpose of helping architects and engineers in the process of selecting the optimal solution of windows for dwellings. It can be used during the design phase of new dwellings or for the renovation of existing ones.

Built in Microsoft Office Excel 2007 and Visual Basic for Applications (VBA), the tool aims to be user-friendly and based on simple input data. At the same time, it is adapted to different expertise levels: for example the inexperienced user has the option of using pre-defined solutions and default suggestions, while the experienced user can have a very high level of flexibility.

The method/tool organizes the process of selecting windows in four different stages named as *Step1*, *Step 2*, *Step 3* and *Step 4*.

In *Step 1*, the user can evaluate and compare the energy performance of different individual windows based on the knowledge of their geometries and components (glazing and frame). This first evaluation is based on the concept of the net energy gain defined in Nielsen T. R. et. al. (2001).

In *Step2*, picking from the windows previously characterized, the user can define a complete set of windows for a specific dwelling. For each window the user must specify orientation, obstructions from horizon, overhangs and fins and solar shading device. The user can create different sets (scenarios) of windows for the dwelling. Depending on the flexibility of each particular design case, the scenarios may be different regarding several aspects (ex. windows components, windows geometry or windows orientations). On a seasonal basis (winter/summer), the energy consumption of the windows used in the dwelling as well as the energy consumption of the dwelling are calculated for each scenario. The calculation is made taking into account the gain and loss utilization factors for heating and cooling, respectively, according to CEN(2008, ISO 13790).

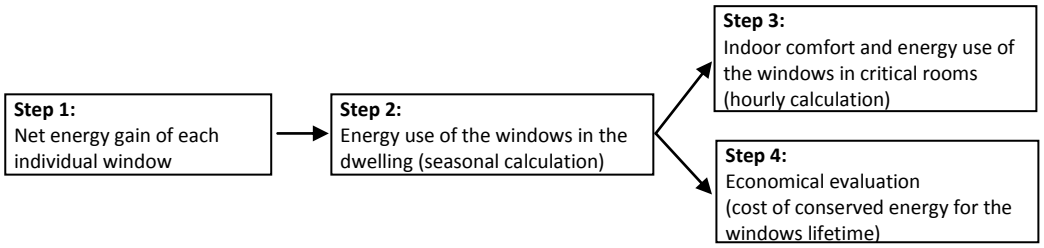
The basis of *Step 3* is the “simple hourly method” defined in CEN(2008, ISO 13790. In this stage the indoor temperature and the heating/cooling energy demand are calculated on an hourly basis for a critical room of the dwelling. The main goal of this stage is to verify whether or not the windows defined for each scenario also allow fulfilling the indoor comfort requirements defined in CEN( 2007, EN 15251).

The *Step 4* consists of an economic evaluation for the scenarios of windows previously defined. In this stage, it is possible to calculate the cost of conserved energy when using the selected windows solutions, in comparison to a reference solution.

Based on the overview of the analyses made during the four steps, the user is, at this stage, able to select the windows solutions with the optimal performance in the actual dwelling.

Furthermore, the user is not obligated to follow the four steps. The user may only use *Step 1* to have a very quick idea of the energy performance of different individual windows with regard to geometry and components. Or the user may use only *Step 2* in order to perform a seasonal calculation knowing previously the U-value and g-value of the windows that he wants to use. *Step 3* and *Step 4* are independent from each other but require *Step 2* to be previously performed.

In *Fig.1* a sketch with the overview of the method and calculation program is presented.




*Figur 2* - Sketch with the overview of the method and calculation program.

# 1 WINDESIGN

**WinDesign** er et program/værktøj, der kan optimere valget af vinduesløsninger til boliger i den tidlige designfase. Det kan anvendes både til design af nybyggeri eller ved renovering af eksisterende boliger. Optimering kan både foretages ud fra den energimæssige ydeevne og den termiske komfort (indetemperatur).

**WinDesign** består af fire niveauer:

STEP 1 – Energitilskud for individuelle vinduer med forskellig geometri og komponenter

STEP 2 – Vinduernes energiforbrug anvendt i en bolig. Sæsonbaseret beregninger.

STEP 3 – Energiforbrug og indetemperatur i et værelse/zone. Timebaseret beregning udført for hver af de forskellige vinduesscenarier.

STEP 4 – Energibesparelsesprisen for de forskellige vinduesscenarier sammenlignet med et reference scenarie.

Baseret på det overblik der opnås gennem de fire STEP vil brugeren være I stand til at foretage et optimeret vinduesvalg til den aktuelle bolig.

***Sådan starter man:***

**WinDesign** er et program udviklet i Microsoft Office Excel 2007 and Visual Basic for Applications og det kan kun anvendes I Microsoft Office Excel 2007. Selvom det er muligt at åbne WinDesign med tidligere versioner af Microsoft Office Excel, så vil resultaterne ikke være troværdige.

For at starte WinDesign udføres de følgende instruktioner:

1. Lav en mappe på din computer med navnet "WinDesign". I denne mappe placeres filen *WinDesign.xlsm* og mappen *Windows*.
2. Set *Windows Regional Options* til *English (United Kingdom)*

   (*Start* > *Settings* > *Control Panel* > *Regional Options*)
3. Start Microsoft Office Excel 2007
4. Check at du har en fuld opdateret version af Microsoft Office. Version: Microsoft® OfficeExcel® 2007 (12.0.6300.5000) SP1 MSO (12.0.6213.1000) eller nyere

   *(Office button > Excel Options > Resources > about Microsoft Office Excel 2007)*

   Hvis du har en ældre version kan opdateringen hentes ved at klikke på "Check for updates". Denne handling kan tage flere minutter og medføre at computeren skal genstartes.
5. Anvend system separatorer

   (*Office button* > *Excel Options* > *Advanced* > Activate the check box: *Use system separators*)
6. Aktiver makroer

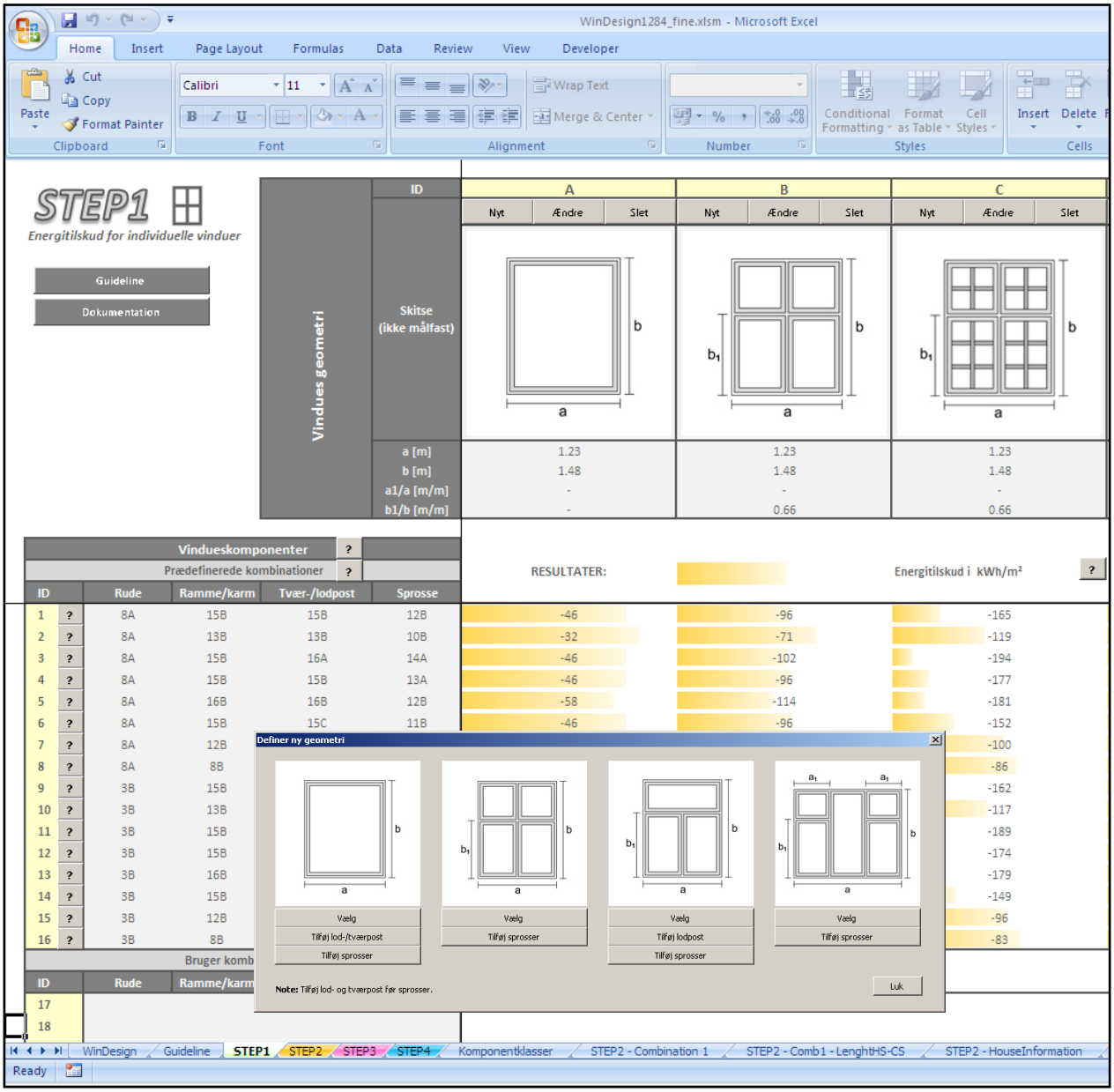
   (*Office button* > *Excel Options* > *Trust Center* > *Trust Center Settings…* > Activate the check box*: Enable All Macros (not recommended; potentially dangerous code can run)*)

   Husk at deaktiver makroer efter brugen af programmet.
7. Åben filen *WinDesign.xlsm*
8. Læs guidelines under hvert STEP

## 1.1 Brugerfladen

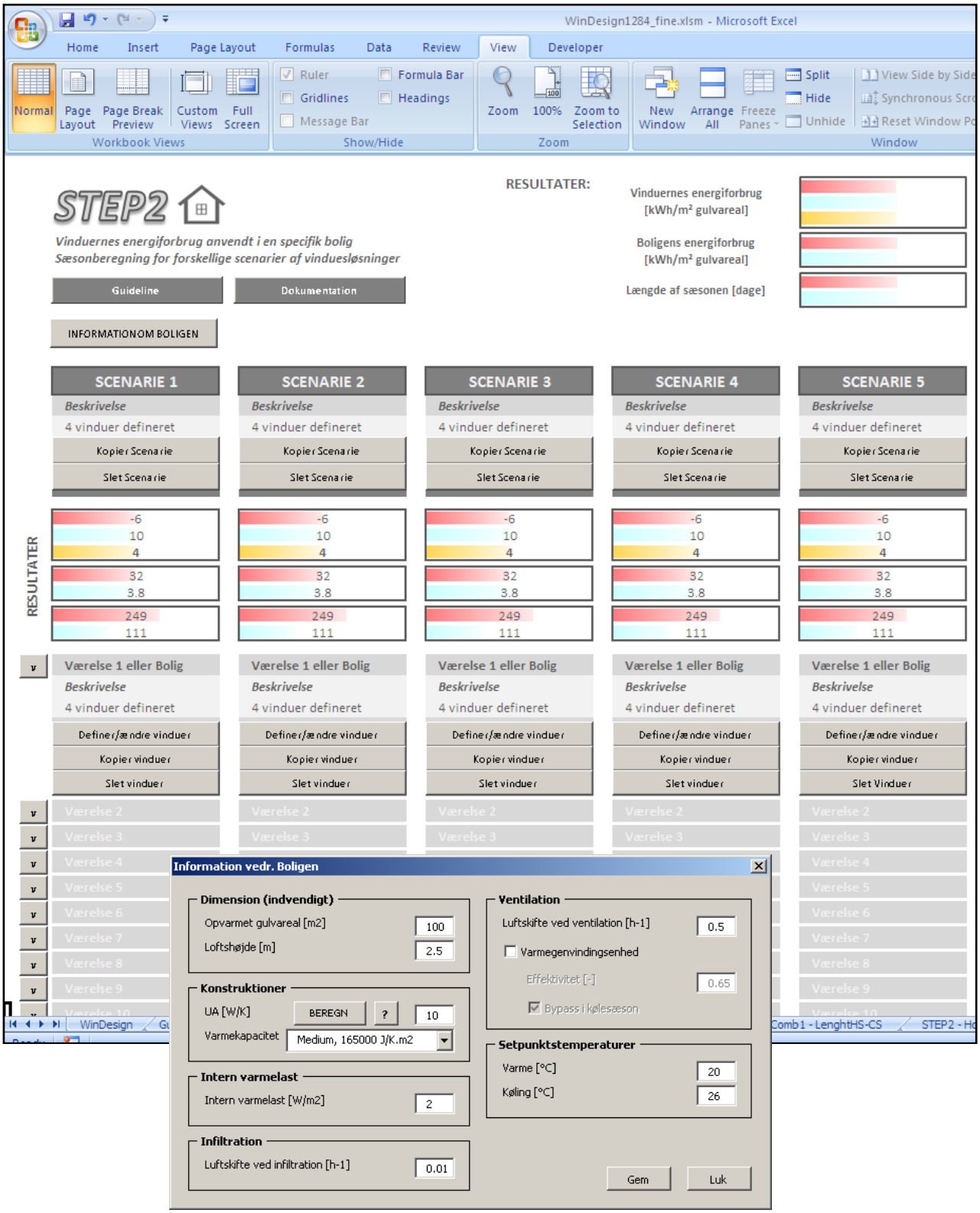
WinDesigns simple brugerflade præsenteres i det følgende med en række screendumps fra de fire STEPs. Fra hvert STEP er det muligt at hente en guideline eller en dokumentations rapport, der i detaljer beskriver de forskellige inputs og beregninger for det respektive STEP.

***STEP 1 - Energitilskud for individuelle vinduer med forskellig geometri og komponenter***




*Figur 3 Screendump from STEP 1*

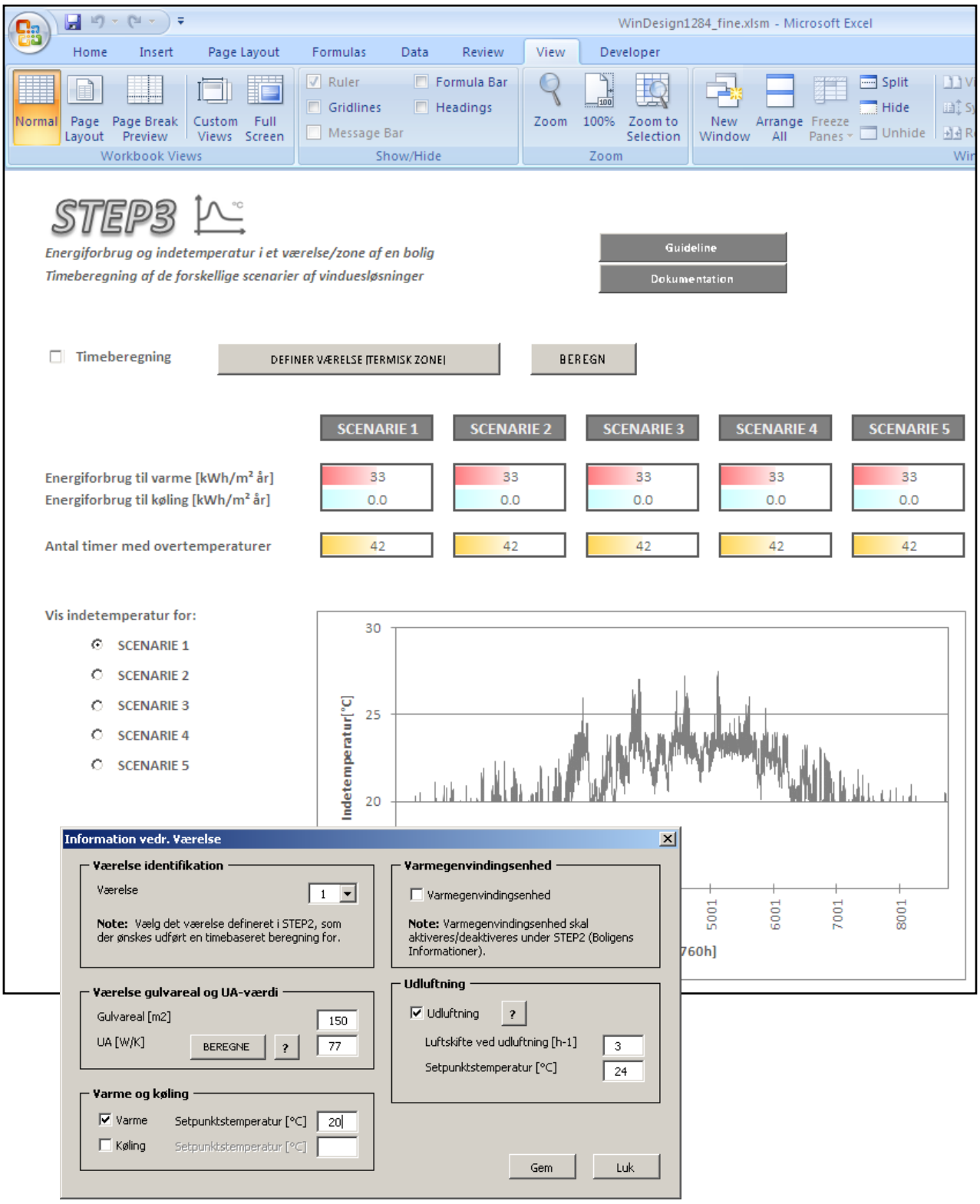
***STEP 2 - Vinduernes energiforbrug anvendt i en bolig. Sæsonbaseret beregning for forskellige løsninger***




*Figur 4 Screendumps from STEP 2*

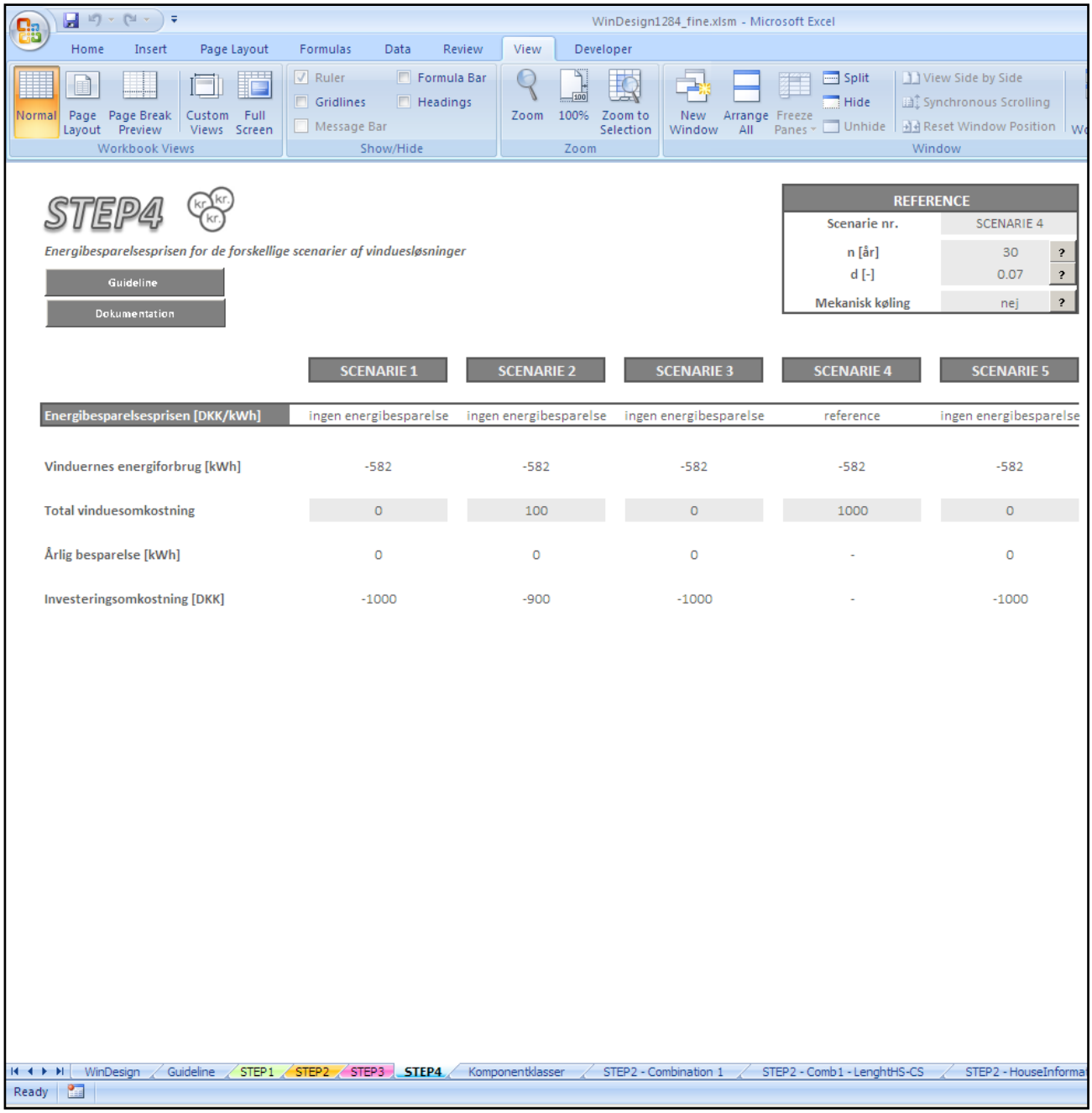
***STEP 3 - Energiforbrug og indetemperatur i et værelse/zone.***

***Timebaseret beregning udført for hver af de forskellige vindues scenarier.***




*Figur 5 Screendumps from STEP 3*

**STEP 4 - Energibesparelsesprisen for de forskellige vindues scenarier sammenlignet med et reference scenarie.**



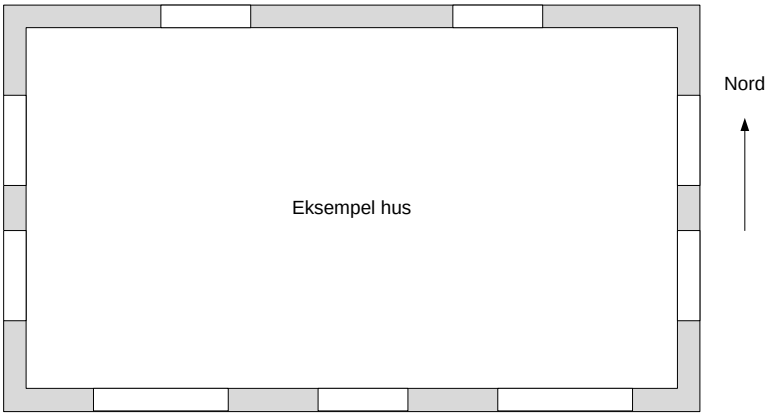

*Figur 6 Screendumps from STEP 4*

## 1.2 Eksempel på optimering med WinDesign

I det følgende gives et eksempel på hvorledes valget af en vinduesløsningen til en bolig kan optimeres med WinDesign. Der tages udgangspunkt i følgende eksempelhus. Husets eksisterende vinduer er 20 år gamle og skal udskiftes.

**Bolig informationer:**

| | |
|---|---|
| Areal | 150 m² |
| Lofthøjde | 2,4 m |
| UA-Værdi | 77 W/K |
| Varmegenvinding | Nej |
| Mekanisk køling | Nej |



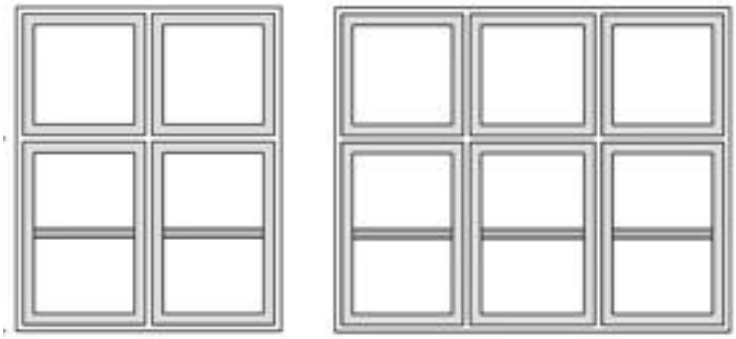

*Figur 7 Plan af eksempelhus*

Huset har to størrelser vinduer som vist i Figur 8.

*Tabel 1 Oversigt over vinduerne*

| | Vinduer | | Nb. | Areal [m²] | Horisont (°) | Udhæng (°) | Side fin venstre (°) | Side fin højre (°) |
|---|---|---|---|---|---|---|---|---|
| 1 | Type A | Vindue lille, 1,00 x1,40m | 7 | 1.4 | 15 | 40 | 0 | 0 |
| 2 | Type B | Vindue stort, 1,50 x1,40m | 2 | 2.1 | 15 | 40 | 0 | 0 |

De eksisterende vinduestyper ses på Figur 8.



Lille vindue Stort vindue

*Figur 8 Eksempelhusets eksisterende vinduer*

Ved udskiftning af husets vinduer ønskes en analyse af forskellige løsningsforslag foretaget med WinDesign. Der ses i eksemplet bort fra døre, men disse kan implementeres ved separat angivelse af areal, U-værdi og evt g-værdi for rudefeltet.

# Indtastning i WinDesign

## STEP1 - Energitilskud for individuelle vinduer

Først klikkes på ”ny”  og de eksisterende vinduer indtastes som type A og B. Der ønskes samme type nye vinduer, dog vil man gerne undvære sprossen. De nye vinduer indtastes som type C og D.

Den eksisterende vinduesløsnings komponenter opbygges i nederst venstre hjørne. De eksisterende vinduer er trævinduer med almindelige termoruder og en aluminiums kantkonstruktion. Referencen til disse kan ses under fanebladet ”Vindueskomponentklasser”. Ruden er en type 18A, Ramme/karm og lodpost en type 15B og sprosse type 12B.

Under STEP1 ses midt for til venstre en række standard komponent løsninger og til højre for disse ses den tilhørende beregning af energitilskuddet. Se Figur 9.

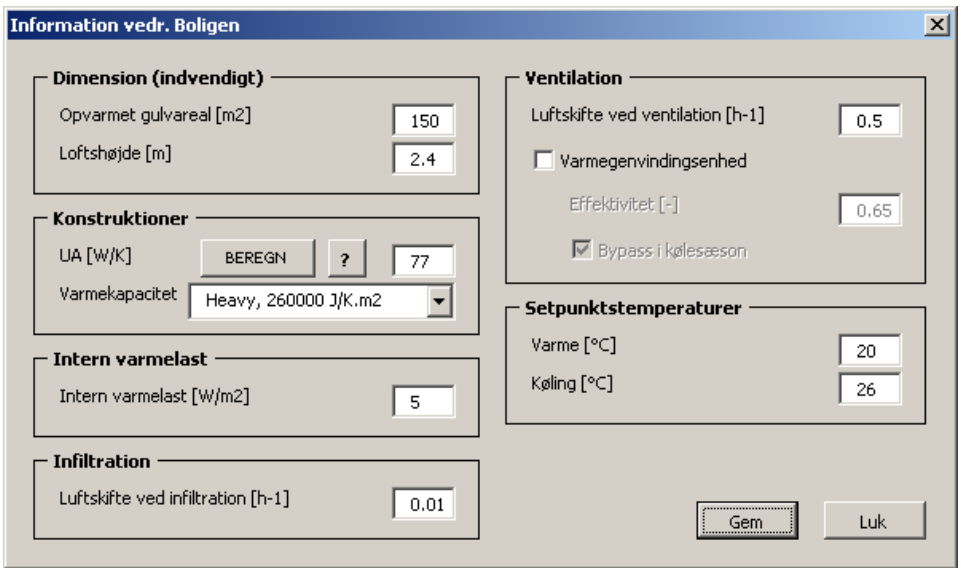
*Figur 9 Screendump efter indtastning af gamle (Type A og B) og nye (C og D) vinduer i STEP1*

På bagrund af energitilskudsberegningen for de forskellige prædefinerede komponentløsninger vælges det at arbejde videre med vinduer af standard træ (krav fra boligejeren) og en traditionel energirude med og uden varme kant og en trelags energirude med varm kant.

Sammenlignes de eksisterende vinduer med de valgte ses at energitilskuddet forbedres med ca. 100 kWh/m² vindue. Besparelsen kan dog variere meget alt efter hvilken bolig vinduerne anvendes i. Dette kan undersøges mere detaljeret i STEP2.

## STEP 2 - Vinduernes energiforbrug anvendt i en specifik bolig

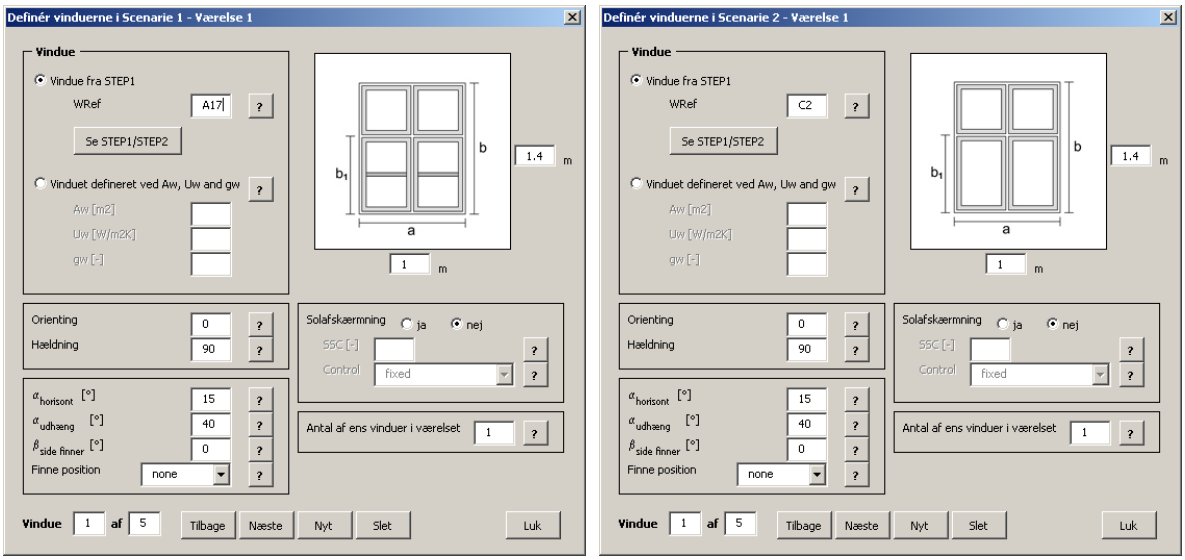
Først klikkes øverst til højre på ”Information om boligen”, hvor de relevante data til energiberegningen indtastes. På Figur 10 ses de indtastede data for eksempelboligen.




*Figur 10 Data til beregningen af boligens energiforbrug til varme og køling (sæson baseret beregning)*

Efter at boligens informationer er indtastet oprettes forskellige scenarier for vinduesløsninger til den specifikke bolig. På Figur 11 ses, hvordan to scenarier oprettes. Scenarie 1 er den eksisterende vinduesløsning og Scenarie 2 er én af de forbedrede løsninger fundet under STEP1. Da antallet af vinduer, orientering mm skal være ens for de to scenarier kan scenarie 1 kopiers direkte videre til scenarie 2, hvorved kun  referencen til vinduerne (fra STEP1) skal ændres. Således ændres for det lille vindue fx A17 (eksisterende vindue) til C2 (nyt vindue).

**Scenarie 1** **Scenarie 2**

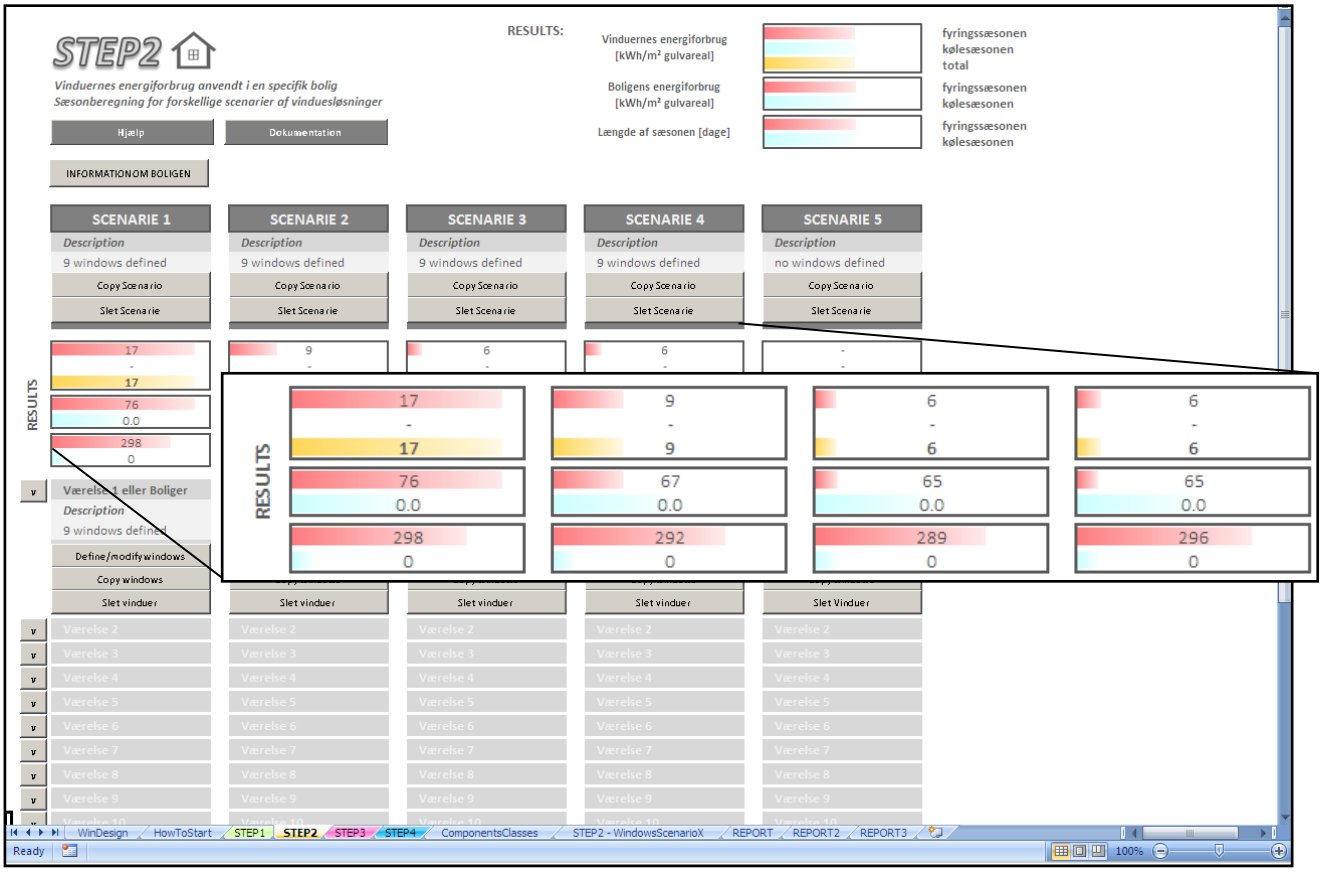



*Figur 11 Indtastning af de to forskellige vinduesscenarier. Til venstre ses det eksisterende lille vindue med sprosseløsning, termorude og standard kant (Reference A17 jf. STEP1) og til højre ses den valgt løsning uden sprosse, energirude og varm kant (C2).*

Efter at alle vinduerne er oprette i scenarierne kan resultat direkte aflæses for både vinduernes energiforbrug pr. m² gulvareal og boligens energiforbrug pr. m² gulvareal. På Figur 12 ses et zoom af resultater fra STEP2.

Der haves således fire scenarier:

- Scenarie 1 Eksisterende vinduesløsning
- Scenarie 2 Vinduer med 2-lags energirude og kold kant
- Scenarie 3 Vinduer med 2-lags energirude og varm kant
- Scenarie 4 Vinduer med 3-lags energirude og varm kant

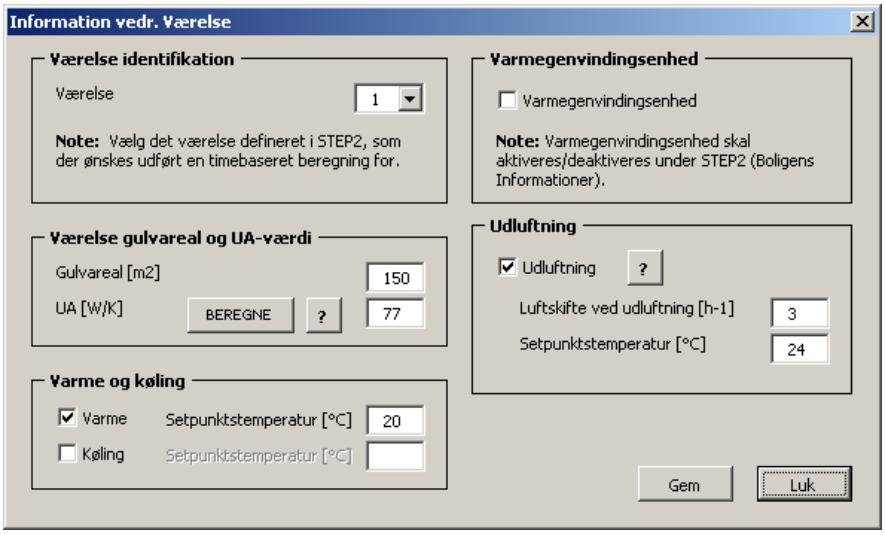



*Figur 12 Sammenligning af resultater for de forskellige scenarier. Det ses at energiforbruget til varme reduceres fra 76 kWh/m² til kun 65 kWh/m².*

Besparelse for vinduesløsningen med en standard 3-lags energirude ses at være den samme som for samme løsning med en 2-lags energirude, hvilket skyldes at 3-lags rudens bedre isoleringsevne modsvares af en dårligere solenergitransmittans, hvilket gør at 3-lags ruden i dette boligeksempel yder som en 2-lags energirude.

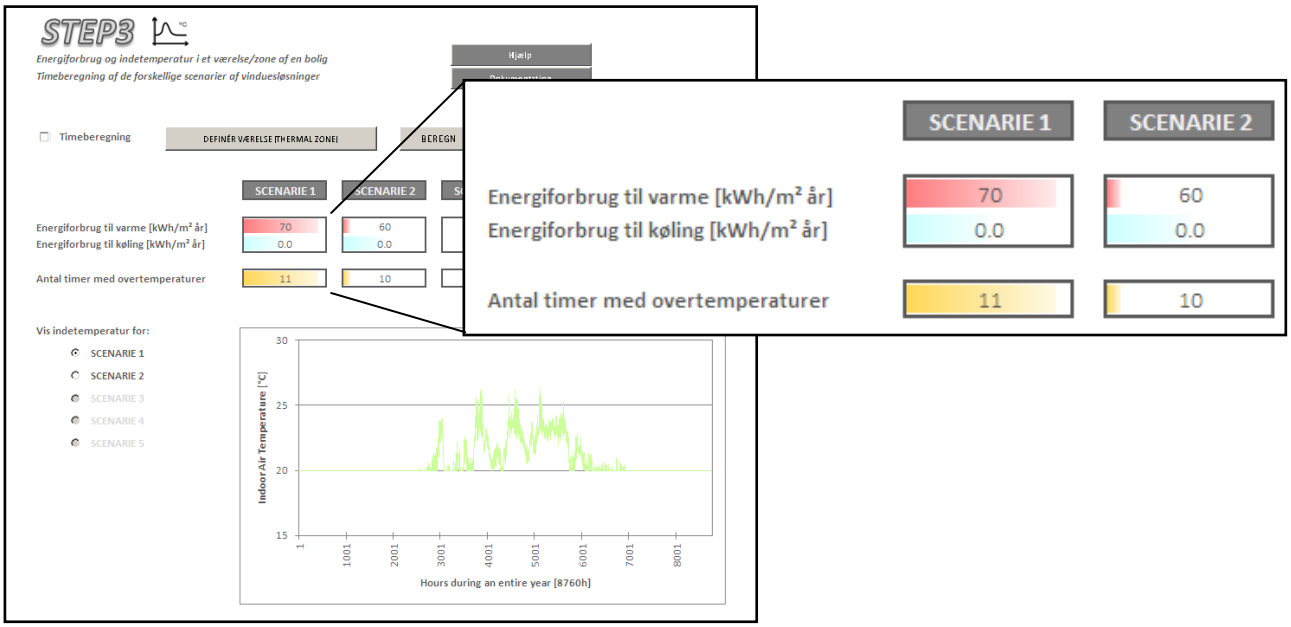
## STEP 3 - Energiforbrug og indetemperatur i et værelse/zone

I STEP3 kan der udføres en mere detaljeret beregning for et udvalgt værelse/zone i boligen. I dette eksempel er der kun oprettet en zone svarende til hele boligen. Da beregningen udføres for hele boligen er dataene til den timebaserede beregning de samme som for boligen jf. STEP2. Figur 13 viser de indtastede data.




*Figur 13 Angivelse af data til den timebaserede årsberegning for boligen.*

Timeberegningen er som default deaktiveret. Når denne aktiveres skal der efterfølgende klikkes på ”Beregn” knappen. Herefter beregnes energiforbrug og antal timer med overtemperaturer for hvert Scenarie. Figur 14 viser et zoom af resultatet for scenarie 1 og 2. Det ses at energiforbruget til opvarmning er lidt lavere end ved STEP2, men at forskellen mellem de to ca. er den samme (10 kWh/m²). Vigtigst er dog at bemærke at der kun er få timer med overtemperaturer i boligen.




*Figur 14 Detaljeret timeberegning af energiforbrug og indetemperatur i boligen for scenarie 1 og 2*

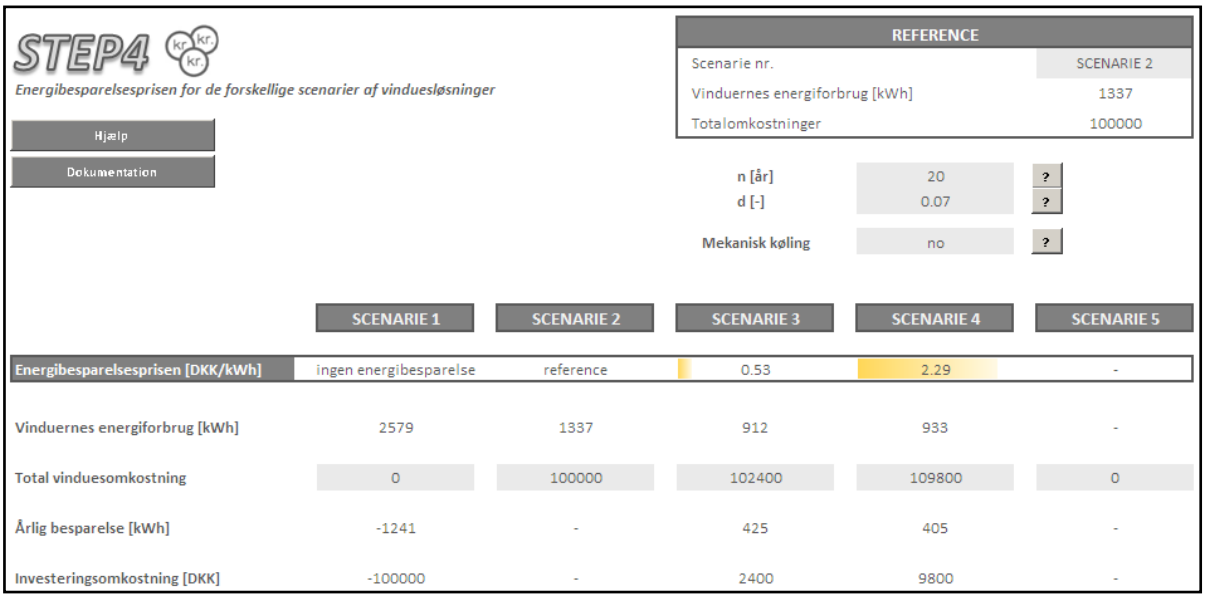
## STEP 4 - Energibesparelsesprisen for de forskellige scenarier af vinduesløsninger

I STEP 4 kan de forskellige scenarier sammenlignes økonomisk. Boligejeren har fået et tilbud på de ønskede trævinduer på ca. 100.000,-. Der oplyses en levetid på vinduerne på ca. 20 år og der anvendes en rente af investeringen på 7 %. Boligejeren har desuden fået oplyst at merprisen for vinduer med varm kant er 25 kr./m og 500 kr/m² for 3-lags energiruder. Tabel 2 viser et overslag for de forventede ekstra omkostninger.

*Tabel 2 Ekstra omkostning ved trelagsrude og varm kant.*

| **Varmkant** | Antal | Længde [m] | I alt [m] |
|---|---|---|---|
| Lille vindue | 7 | 9.6 | 67.2 |
| Stort vindue | 2 | 14.4 | 28.8 |
| Total længde | | | 96 |
| **Ekstra omkostning varm kant** | | **25 kr./m** | **2400 kr.** |
| **Trelagsrude** | | | 500 kr. m² |
| Antal m² | | | 10 m² |
| Ekstra omkostning 3-lagsenergirude | | | 5.000 kr. |
| **Samlet ekstra omkostning 3-lags rude (inkl. 2 x varm kant)** | | | **9.800 kr.** |

Overslagberegninger fra Tabel 2 indtastes i STEP 4. Det vælges at anvende scenarie 2 som reference, idet scenarie 1 blot viser den eksisterende løsning. STEP 4 skal nu bruges til at vurdere hvilket at scenarierne 2, 3 og 4, der er mest økonomisk fordelagtig for boligejeren. Figur 15 viser denne sammenligning fra STEP 4. Det ses at meromkostningen ved scenarie 3 (varme kanter) resulterer i en energibesparelsespris på kun 0,53 kr./kWh. For 3-lags energirude er energibesparelsesprisen noget højre, 2,29 kr./kWh, men kan dog i nærmeste fremtid vise sig at være en acceptabel energipris alligevel.




*Figur 15 Økonomisk overblik fra STEP 4.*

# 2 DOKUMENTATION AF BEREGNINGSKERNE (engelsk)

WinDesign is designed in Microsoft Office Excel 2007 and VBA. The file WinDesign.xlsm contains 45 worksheets, 75 userforms and 6 modules. However only 10 worksheets are displayed to the user: “WinDesign”, “Guideline”, “STEP1”, “STEP2”, “STEP3”, “STEP4”,” Komponentklasser”, “RAPPORT1”, “RAPPORT2” and “RAPPORT3”.

The worksheets are protected to avoid misuse. However if the user is interested in looking into the calculation in detail, the password “bygdtu” can be used to unprotect the worksheets.

Also the VBA code is protected. The password to unprotect it is the same, “bygdtu”.

In this section a description of the calculation method used in the program is presented. The section is organized in four different subsections corresponding respectively to Step 1, Step 2, Step 3 and Step 4.

## 2.1 STEP 1 - Net energy gain of individual windows

### 2.1.1 The goal

In this first step, the purpose is to express, in an easy and simple way, the energy performance of different individual windows varying in geometry and components (glazing, frame, transoms, mullions and glazing bars). The concept used for this purpose is the net energy gain defined in (Nielsen T. R. et. al., 2001).

### 2.1.2 Net energy gain

The net energy gain of a window is the difference between the solar gains and the heat losses that occur through that window during the heating season. It is calculated for a reference house located in Denmark according to the following equation:

$$E_{ref} = I \cdot g_w - D \cdot U_w = 196.42 \cdot g_w - 90.36 \cdot U_w \; [kWh/m^2] \qquad (1)$$

where:

$I = 194.42 kWh/m^2$ is the solar radiation calculated for the reference house during the heating season;

$D = 90.36 kKh$ is the degree hour number during the heating season in Denmark;

$U_w$ is the thermal transmittance of the window, calculated in accordance with 2.1.3, expressed in $W/m^2$K;

$g_w$ is the total solar energy transmittance of the window, calculated in accordance with 2.1.4 (no units).

Both I and D are calculated using the Danish Reference Year (Jensen J.M. and Lund H., 1995)).

The net energy gain of a window indicates its energy performance during the heating season when used in the reference house. The window is considered to have an average orientation correspond-

ing to the distribution of windows in the reference house (North 26%; South: 41% and East/West: 33%) and all the solar gain is assumed to be utilized for heating.

### 2.1.3 Thermal transmittance of windows

The thermal transmittance of a window, $U_w$, is calculated according to:

$$U_w = \frac{U_g \cdot A_g + L_{joint,f} \cdot l_f + L_{joint,m/t} \cdot l_{m/t} + L_{joint,gb} \cdot l_{gb}}{A_w} \; [W/m^2K] \qquad (2)$$

where:

$U_g$ is the thermal transmittance of the glazing, expressed in $W/m^2K$;

$A_g$ is the area of the glazing, calculated in accordance with 2.1.7, expressed in $m^2$;

$L_{joint,f}$ is the thermal transmittance of the frame/sash profile, calculated in accordance with 2.1.5, expressed in $W/mK$;

$l_f$ is the length of the frame/sash profile, calculated in accordance with 2.1.6, expressed in *m*;

$L_{joint,m/t}$ is the thermal transmittance of the mullions/ transoms profile, calculated in accordance with 2.1.5, expressed in $W/mK$;

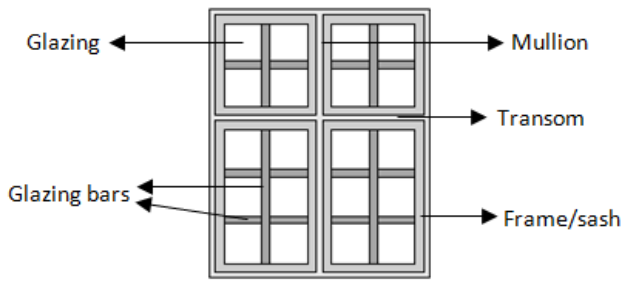
$l_{m/t}$ is the length of the mullions and transoms profile, calculated in accordance with 2.1.6, expressed in *m*;

$L_{joint,gb}$ is the thermal transmittance of the glazing bars profile, calculated in accordance with 2.1.5, expressed in $W/mK$;

$l_{gb}$ is the length of the glazing bars profile, calculated in accordance with 2.1.6, expressed in *m*;

$A_w$ is the area of the window in $m^2$.

The following figure illustrates the different window components previously mentioned.




*Figur 16 Illustration of the different window components*

### 2.1.4 Total solar energy transmittance of windows

The total solar energy transmittance of a window, $g_w$, is calculated according to:

$$g_w = \frac{g_g \cdot A_g}{A_w} \; [-] \qquad (3)$$

where:

$g_g$ is the total solar energy transmittance of the glazing (no units);

$A_g$ is the area of the glazing, calculated in accordance with 2.1.7, expressed in $m^2$;

$A_w$ is the area of the window, expressed in $m^2$.

### 2.1.5 Thermal transmittance of the frame/sash, mullions/transoms and glazing bars profiles

The thermal transmittance of the frame/sash, mullions/transoms and glazing bars profiles, respectively $L_{joint,f}$ , $L_{joint,m/t}$ and $L_{joint,gb}$ are calculated according to:

$$L_{joint,f} = U_f \cdot w_f + \Psi_{f,g} \; [W/mK] \qquad (4)$$

$$L_{joint,m/t} = U_{m/t} \cdot w_{m/t} + 2\Psi_{m/t,g} \; [W/mK] \qquad (5)$$

$$L_{joint,gb} = U_{gb} \cdot w_{gb} + 2\Psi_{gb,g} \; [W/mK] \qquad (6)$$

where:

$U_f$ is the thermal transmittance of the frame/sash profile in $W/m^2K$;

$w_f$ is the width of the frame/sash profile in $m$;

$\Psi_{f,g}$ is the linear thermal transmittance due to the combined effects of the glazing, spacer and frame/sash profile in $W/m$K;

$U_{m/t}$ is the thermal transmittance of the mullion/transom profile in $W/m^2K$;

$w_{m/t}$ is the width of the mullion/transom profile in $m$;

$\Psi_{m/t,g}$ is the linear thermal transmittance due to the combined effects of the glazing, spacer and mullion/transom profile in $W/m$K;

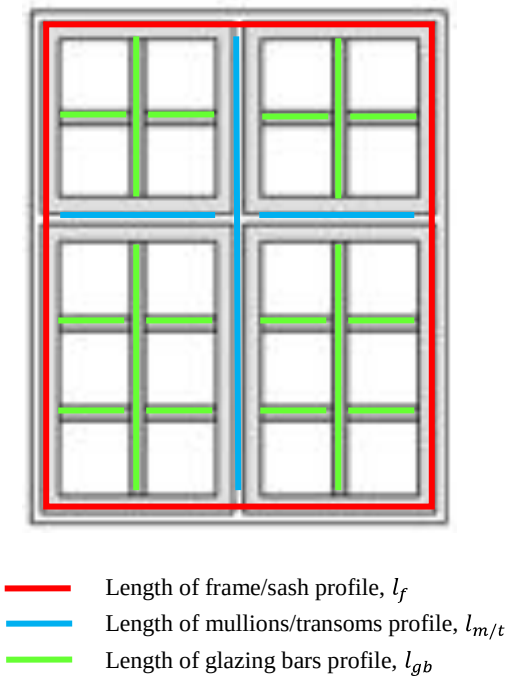
$U_{gb}$ is the thermal transmittance of the glazing bar profile in $W/m^2K$;

$w_{gb}$ is the width of the glazing bar profile in $m$;

$\Psi_{gb,g}$ is the linear thermal transmittance due to the combined effects of the glazing, spacer and glazing bar profile in $W/m$K.

### 2.1.6 Length of the frame/sash, mullions/transoms and glazing bars profiles

The calculation of the length of the different profiles is made for each window according to the following figure:




*Figur 17 Illustration of how the length of the different profiles is calculated.*

### 2.1.7 Area of the glazing

The area of the glazing is calculated according to:

$$A_g = A_w - (A_f + A_{m/t} + A_{gb})\ [m^2] \qquad (7)$$

where:

$A_w$ is the area of the window, expressed in $m^2$;

$A_f$ is the area of the frame/sash profile, calculated in accordance with 2.1.8, expressed in $m^2$;

$A_{m/t}$ is the area of the mullions/transoms profiles, calculated in accordance with 2.1.8, expressed in $m^2$;

$A_{gb}$ is the area of the glazing bars profiles, calculated in accordance with 2.1.8, expressed in $m^2$;

### 2.1.8 Area of the frame/sash, mullions/transoms and glazing bars profiles

The areas of the frame/sash, mullions/transoms and glazing bars profiles are calculated according to:

$$A_f = l_f w_f \ \ [m^2] \tag{8}$$

$$A_{m/t} = l_{m/t} w_{m/t} \ \ [m^2] \tag{9}$$

$$A_{gb} = l_{gb} w_{gb} \ \ [m^2] \tag{10}$$

where:

$l_f$ is the length of the frame/sash profile, calculated in accordance with 2.1.6, expressed in *m*;

$w_f$ is the width of the frame/sash profile in $m$;

$l_{m/t}$ is the length of the mullions and transoms profile, calculated in accordance with 2.1.6, expressed in *m*;

$w_{m/t}$ is the width of the mullion/transom profile in $m$;

$l_{gb}$ is the length of the glazing bars profile, calculated in accordance with 2.1.6, expressed in *m*;

$w_{gb}$ is the width of the glazing bar profile in $m$.

### 2.1.9 Energy classes for glazing, frame/sash, mullions/transoms and glazing bars

The window components are organized in energy classes.

For the glazings, the energy classes are sorted by:

$U_g$- thermal transmittance of the glazing in $W/m^2K$;

$g_g$- total solar energy transmittance (no units).

For the frame/sash, mullions/transoms and glazing bars profiles, the energy classes are sorted by:

$L_{joint}$ - thermal transmittance of the profile, calculated in accordance with 2.1.5, expressed in $W/mK$;

$w$ - width of the profile in $m$.

For the calculations, the average of the lowest and highest limits of the class is used. For instance, for the glazing class 1A which corresponds to $0.5 < U_g < 0.6\ W/m^2K$ and $0.5 < g_g < 0.6\ W/m^2K$, the calculation is performed using $U_g = 0.55\ W/m^2K$ and $g_g = 0.55$. (Figur 18)

| Glazing | | | | |
|---|---|---|---|---|
| ID | Class | Description | $U_g$ [W/m$^2$K] | $g_g$ [-] |
| 1 | 1A | $0.5 \le U_g < 0.6$; $0.5 < g_g \le 0.6$ | 0.55 | 0.55 |
| 2 | 1B | $0.5 \le U_g < 0.6$; $0.4 < g_g \le 0.5$ | 0.55 | 0.45 |
| 3 | 1C | $0.5 \le U_g < 0.6$; $0.3 < g_g \le 0.4$ | 0.55 | 0.35 |
| 4 | 1D | $0.5 \le U_g < 0.6$; $0.2 < g_g \le 0.3$ | 0.55 | 0.25 |
| 5 | 1E | $0.5 \le U_g < 0.6$; $0.1 \le g_g \le 0.2$ | 0.55 | 0.15 |
| 6 | 2A | $0.6 \le U_g < 0.7$; $0.5 < g_g \le 0.6$ | 0.65 | 0.55 |
| 7 | 2B | $0.6 \le U_g < 0.7$; $0.4 \le g_g \le 0.5$ | 0.65 | 0.45 |
| 8 | 2C | $0.6 \le U_g < 0.7$; $0.3 < g_g \le 0.4$ | 0.65 | 0.35 |
| 9 | 2D | $0.6 \le U_g < 0.7$; $0.2 \le g_g \le 0.3$ | 0.65 | 0.25 |
| 10 | 2E | $0.6 \le U_g < 0.7$; $0.1 \le g_g \le 0.2$ | 0.65 | 0.15 |
| 11 | 3A | $0.7 \le U_g < 0.8$; $0.5 < g_g \le 0.6$ | 0.75 | 0.55 |
| 12 | 3B | $0.7 \le U_g < 0.8$; $0.4 < g_g \le 0.5$ | 0.75 | 0.45 |
| 13 | 3C | $0.7 \le U_g < 0.8$; $0.3 < g_g \le 0.4$ | 0.75 | 0.35 |
| 14 | 3D | $0.7 \le U_g < 0.8$; $0.2 < g_g \le 0.3$ | 0.75 | 0.25 |
| 15 | 3E | $0.7 \le U_g < 0.8$; $0.1 \le g_g \le 0.2$ | 0.75 | 0.15 |
| 16 | 4A | $0.8 \le U_g < 0.9$; $0.5 < g_g \le 0.6$ | 0.85 | 0.55 |
| 17 | 4B | $0.8 \le U_g < 0.9$; $0.4 < g_g \le 0.5$ | 0.85 | 0.45 |

| Frame/Sash | | | | |
|---|---|---|---|---|
| ID | Class | Description | $L_{joint,f}$ [W/mK] | $w_f$ [m] |
| 1 | 1A | $0.05 \le L_{joint,f} < 0.06$; $0.04 \le w_f < 0.05$ | 0.055 | 0.045 |
| 2 | 2A | $0.06 \le L_{joint,f} < 0.07$; $0.04 \le w_f < 0.05$ | 0.065 | 0.045 |
| 3 | 3A | $0.07 \le L_{joint,f} < 0.08$; $0.04 \le w_f < 0.05$ | 0.075 | 0.045 |
| 4 | 3B | $0.07 \le L_{joint,f} < 0.08$; $0.05 \le w_f < 0.10$ | 0.075 | 0.075 |
| 5 | 4A | $0.08 \le L_{joint,f} < 0.09$; $0.04 \le w_f < 0.05$ | 0.085 | 0.045 |
| 6 | 4A | $0.08 \le L_{joint,f} < 0.09$; $0.05 \le w_f < 0.10$ | 0.085 | 0.075 |
| 7 | 5A | $0.09 \le L_{joint,f} < 0.10$; $0.04 \le w_f < 0.05$ | 0.095 | 0.045 |
| 8 | 5B | $0.09 \le L_{joint,f} < 0.10$; $0.05 \le w_f < 0.10$ | 0.095 | 0.075 |
| 9 | 5C | $0.09 \le L_{joint,f} < 0.10$; $0.10 \le w_f < 0.15$ | 0.095 | 0.125 |
| 10 | 6A | $0.10 \le L_{joint,f} < 0.11$; $0.04 \le w_f < 0.05$ | 0.105 | 0.045 |
| 11 | 6B | $0.10 \le L_{joint,f} < 0.11$; $0.05 \le w_f < 0.10$ | 0.105 | 0.075 |
| 12 | 6C | $0.10 \le L_{joint,f} < 0.11$; $0.10 \le w_f < 0.15$ | 0.105 | 0.125 |
| 13 | 7A | $0.11 \le L_{joint,f} < 0.12$; $0.04 \le w_f < 0.05$ | 0.115 | 0.045 |
| 14 | 7B | $0.11 \le L_{joint,f} < 0.12$; $0.05 \le w_f < 0.10$ | 0.115 | 0.075 |
| 15 | 7C | $0.11 \le L_{joint,f} < 0.12$; $0.10 \le w_f < 0.15$ | 0.115 | 0.125 |
| 16 | 8A | $0.12 \le L_{joint,f} < 0.13$; $0.04 \le w_f < 0.05$ | 0.125 | 0.045 |
| 17 | 8B | $0.12 \le L_{joint,f} < 0.13$; $0.05 \le w_f < 0.10$ | 0.125 | 0.075 |
| 18 | 8C | $0.12 \le L_{joint,f} < 0.13$; $0.10 \le w_f < 0.15$ | 0.125 | 0.125 |

*Figur 18 Energy classes for glazings and frame/sash profiles*

*(image from the user interface of the program)*

## 2.2 STEP 2 - Energy consumption of the windows used in the dwelling - Seasonal calculation

### 2.2.1 The Goal

In Step 2, the purpose is to evaluate, on a seasonal basis, the energy consumption of a complete set of windows used in a specific dwelling located in Denmark. The calculation is performed according to CEN (2008, ISO 13790) and using the Design Reference Year (Jensen J.M. and Lund H., 1995) as the weather input.

For this calculation, the dwelling is assumed to be one single thermal zone, even though the user defines the windows per room.

### 2.2.2 Seasonal energy consumption of each window used in the dwelling

The energy use of each window i in the dwelling is calculated for the heating and cooling seasons according to the following equations:

(the length of the heating and cooling seasons are calculated for each specific dwelling in accordance with 2.2.11.1 and 2.2.11.2)

$$E_{i,HS} = U_{w,i} \cdot A_{w,i} \cdot G_{HS} - \eta_{HS,gn} \cdot F_{sh,ob,i,HS} \cdot A_{sol,i,HS} \cdot I_{sol,i,HS} \quad [kWh] \qquad (11)$$

$$E_{i,CS} = F_{sh,ob,i,CS} \cdot A_{sol,i,CS} \cdot I_{CS,ls} - \eta_{ls,CS} \cdot U_{w,i} \cdot A_{w,i} \cdot G_{CS} \quad [kWh] \qquad (12)$$

where:

$E_{i,HS}$ is the energy consumption of each window i during the heating season in $kWh$;

$E_{i,CS}$ is the energy consumption of each window i during the cooling season in $kWh$;

$U_{w,i}$ is the thermal transmittance of the window i in $W/m^2K$;

$A_{w,i}$ is the area of the window i in $m^2$;

$G_{HS}$ is the number of degree-hours during the heating season, determined in accordance with 2.2.7, expressed in $kKh$;

$G_{CS}$ is the number of degree-hours during the cooling season in kKh, determined in accordance with 2.2.7, expressed in $kKh$;

$F_{sh,ob,i,HS}$ is the shading reduction factor due to external obstacles for the window i for the heating season, determined in accordance with 2.2.4 (no units);

$F_{sh,ob,i,CS}$ is the shading reduction factor due to external obstacles for the window i for the cooling season (no units), determined in accordance with 2.2.4 (no units);

$A_{sol,i,HS}$ is the effective collecting area of the window i with a given orientation and tilt angle for the heating season, determined in accordance with 2.2.5, expressed in $m^2$.

$A_{sol,i,CS}$ is the effective collecting area of the window i with a given orientation and tilt angle for the cooling season, determined in accordance with 2.2.5, expressed n $m^2$.

$I_{sol,i,HS}$ is the total solar radiation per square metre of the window area i, with a given orientation and tilt angle, over the heating season, determined in accordance with 2.2.6, expressed in $kWh/m^2$;

$I_{sol,i,CS}$ is the total solar radiation per square metre of the window area i, with a given orientation and tilt angle, over the cooling season, determined in accordance with 2.2.6, expressed in $kWh/m^2$;

$\eta_{HS,gn}$ is the dimensionless utilization factor for the solar gains during the heating season, calculated in accordance with 2.2.8.1;

$\eta_{CS,ls}$ is the dimensionless utilization factor for the heat losses during the cooling season, calculated in accordance with 2.2.8.2.

### 2.2.3 Seasonal energy consumption of a complete set (scenario) of windows used in the dwelling

The total energy consumption of the complete set of windows used in the dwelling for both the heating and cooling seasons is obtained by summing the energy consumption of each window i:

$$E_{total,HS} = \sum_i \frac{E_{i,HS}}{A_f} [kWh/m^2] \qquad (13)$$

$$E_{total,CS} = \sum_i \frac{E_{i,CS}}{A_f} [kWh/m^2] \qquad (14)$$

where:

$E_{total,HS}$ is the total energy consumption of the complete set of windows used in the dwelling during the heating season in $kWh/m^2$ floor area;

$E_{total,CS}$ is the total energy consumption of the complete set of windows used in the dwelling during the cooling season in $kWh/m^2$ floor area;

$E_{i,HS}$ is the energy consumption of each window i during the heating season in $kWh$, calculated in accordance with 2.2.2;

$E_{i,CS}$ is the energy consumption of each window i during the cooling season in $kWh$, calculated in accordance with 2.2.2;

$A_f$ is the heated floor area of the dwelling in $m^2$

Summing $E_{total,HS}$ and $E_{total,CS}$, the overall energy consumption of the complete set of windows used in the dwelling is obtained for the entire year.

Note: A complete set of windows in the dwelling is referred as a *Scenario* in the program. The user can define up to five different *Scenarios* of windows and compare their energy performance.

### 2.2.4 Shading reduction factor for external obstacles for each window

The shading factor for external obstacles for each window i, is first calculated for each month m (from 1 to 12) and only afterwards for the heating and cooling seasons.

$$F_{sh,ob,i,m} = F_{hor,i,m} F_{ov,i,m} F_{fin,i,m} \; [-] \qquad (15)$$

where:

$F_{sh,ob,i,m}$ is the shading reduction factor for external obstacles for each window i for the month m

$F_{hor,i,m}$ is the partial shading correction factor for the horizon for each window i for the month m

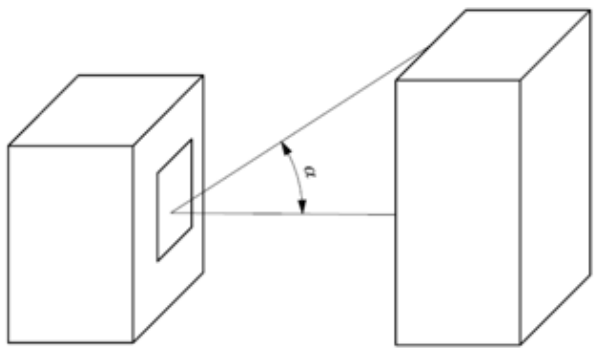
$F_{ov,i,m}$ is the partial shading correction factor for overhangs for each window i for the month m

$F_{fin,i,m}$ is the partial shading correction factor for fins for each window i for the month m

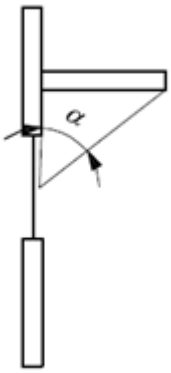
The shading correction factors ($F_{hor}$, $F_{ov}$ and $F_{fin}$) for the Danish climate are available for eight different orientations in a monthly basis in the hidden Worksheet "DRY - Month" in the program (data obtained from Be05, SBi (2006)).

For the horizon, the partial shading factors are available for horizon angles of 10° and 30°; for overhangs, the partial shading factors are available for overhang angles of 45° and 60°; and for fins, the partial shading factors are available for fin angles of 30° and 60°, for fins on the left side, right side or both sides of the window.

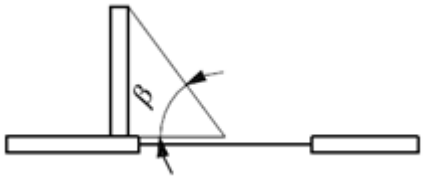
For each window i, the shading factors $F_{hor,i,m}$, $F_{ov,i,m}$ and $F_{fin,i,m}$ are obtained by 2-dimensional linear interpolation of the available values.




*Figur 19 Horizon angle, $\alpha$*




*Figur 20 Overhang angle (vertical section)*




*Figur 21 Fin angle (horizontal section)*

After the lengths of the heating and cooling seasons have been determined (in accordance with 2.2.11.1 and 2.2.11.2), the shading reduction factor due to external obstacles can be calculated, for each window i, for the heating and cooling seasons according to:

$$F_{sh,ob,i,HS} = \frac{\sum_{m=1}^{m=12} l_{j,HS} F_{sh,ob,i,m}}{l_{HS}} \; [-] \qquad (16)$$

$$F_{sh,ob,i,CS} = \frac{\sum_{m=1}^{m=12} l_{j,CS} F_{sh,ob,i,m}}{l_{CS}} \; [-] \qquad (17)$$

where:

$F_{sh,ob,i,HS}$ is the shading reduction factor due to external obstacles for the window i for the heating season (no units);

$F_{sh,ob,i,CS}$ is the shading reduction factor due to external obstacles for the window i for the cooling season (no units);

$F_{sh,ob,i,m}$ is the shading reduction factor for external obstacles for each window i for the month m;

$l_{m,HS}$ is the number of days of each month m belonging to the heating season;

$l_{m,CS}$ is the number of days of each month m belonging to the cooling season;

$l_{HS}$ is the length of the heating season in days;

$l_{CS}$ is the length of the cooling season in days.

<u>Note:</u> The year is assumed to have 365 days according to CEN(2008, ISO 13790).

### 2.2.5 Effective solar collecting area of each window

As the shading factor for external obstacles, also the effective solar collecting area for each window i is first calculated for each month m (from 1 to 12) and only afterwards for the heating and cooling seasons.

The effective solar collecting area of each window i for each month m, $A_{sol,i,m}$, is obtained according to:

$$A_{sol,i,m} = F_{sh,gl,i,m} g_{gl,i} \left(1 - F_{F,i}\right) A_{w,i} \; [m^2] \qquad (18)$$

where:

$F_{sh,gl,i,m}$ is the shading reduction factor for movable shading devices for each window i for the month m, determined in accordance with 2.2.5.1;

$g_{gl,i}$ is the total solar energy transmittance of the glazing of each window i, determined in accordance with 2.2.5.3;

$F_{F,i}$ is the frame area fraction of each window i, ratio of the frame area to the overall window area;

$A_{w,i}$ is the window i area, expressed in $m^2$.

<u>Note:</u> If the window i was defined by $A_w$, $U_w$ and $g_w$ and if there is no information about $g_{gl}$ and $F_F$, the equation *(19)* is used in the following way:

$$A_{sol,i,j} = F_{sh,gl,i,j} g_{w,i} A_{w,i} \; [m^2] \qquad (19)$$

where:

$g_{w,i}$ is the total solar energy transmittance of the window i, determined in accordance with 2.2.5.3;

After the lengths of the heating and cooling seasons have been determined (in accordance with 2.2.11.1 and 2.2.11.2), the effective solar collecting area of each window i for the heating and cooling seasons is calculated according to:

$$A_{sol,i,HS} = \frac{\sum_{j=1}^{j=12} l_{j,HS} A_{sol,i,m}}{l_{HS}} \; [m^2] \qquad (20)$$

$$A_{sol,i,CS} = \frac{\sum_{j=1}^{j=12} l_{j,CS} A_{sol,i,m}}{l_{CS}} \; [m^2] \qquad (21)$$

where:

$A_{sol,i,HS}$ is effective solar collecting area for each window i for the heating season, in $m^2$;

$A_{sol,HS,i}$ is effective solar collecting area for each window i for the cooling season, in $m^2$;

$A_{sol,i,m}$ is effective solar collecting area for each window i for the month m, in $m^2$;

$l_{m,HS}$ is the number of days of the month m belonging to the heating season;

$l_{m,CS}$ is the number of days of the month m belonging to the cooling season;

$l_{HS}$ is the length of the heating season in days;

$l_{CS}$ is the length of the cooling season in days.

Note: The year is assumed to have 365 days according to CEN(2008, ISO 13790).

#### 2.2.5.1 Shading reduction factor for movable shading devices

The shading reduction factor for movable shading devices for each window i is calculated first for each month m and only afterwards for the heating and cooling seasons.

$$F_{sh,gl,i,m} = \frac{[(1-f_{sh,with,i,m})g_{gl,i}+f_{sh,with,i,m}g_{gl+sh,i}]}{g_{gl,i}} \; [-] \qquad (22)$$

where:

$F_{sh,gl,i,m}$ is the shading reduction factor for movable shading devices for each window i for the month m;

$g_{gl,i}$ is the total solar energy transmittance of the glazing of each window i, when the solar shading device is not in use, determined in accordance with 2.2.5.3;

$g_{gl+sh,i}$ is the total solar energy transmittance of the glazing of each window i, when the solar shading device is in use, determined in accordance with 2.2.5.4;

$f_{sh,with,i,m}$ is the weighted fraction of the time with the solar shading in use on the window i during the month m. It is a function of the intensity of the incident solar radiation on the window i surface, determined in accordance to 2.2.5.2.

Note: If the window i was defined by $A_w$, $U_w$ and $g_w$ and if there is no information about $g_{gl}$ and $F_F$, the equation *(22)* is used in the following way:

$$F_{sh,gl,i,m} = \frac{[(1-f_{sh,with,i,m})g_{w,i}+f_{sh,with,i,m}g_{w+sh,i}]}{g_{w,i}} \; [-] \qquad (23)$$

where:

$g_{w,i}$ is the total solar energy transmittance of the window i when the solar shading device is not in use, determined in accordance with 2.2.5.3;

$g_{w+sh,i}$ is the total solar energy transmittance of the window i when the solar shading device is in use, determined in accordance with 2.2.5.4;

#### 2.2.5.2 Weighted fraction of the time with the solar shading in use

According to CEN (2008, ISO 13790) for monthly and seasonal calculation methods, the control of the solar shading device is based on the incident solar radiation on the window surface.

The weighted fraction of the time for which the solar shading device is in use was calculated for each month m and for the eight different vertical surface orientations (North, North/East, East, South/East, South, South/West, West, North/West) according to:

$$f_{sh,with,k,m} = \frac{\sum_{h=1,if\ I_{sol,k,h,m}>300Wh/m^2}^{h=n} I_{sol,k,h,m}}{\sum_{h=1}^{h=n} I_{sol,k,h,m}} \ [-] \qquad (24)$$

where:

$I_{sol,k,h,m}$ is the total solar radiation per square meter of a vertical surface with orientation k, over the hour h of the month m in $Wh/m^2$;

$n$ is the number of hours of the month m.

Note: The results from this calculation are presented in the hidden Worksheet “DRY-Month” in the program.

For each window i with a given orientation, $f_{sh,with,i,m}$ is calculated for each month m by linear interpolation of the previously calculated values $f_{sh,with,k,m}$.

In the program the user can also choose to keep the solar shading device always activated. In this case $f_{sh,with}$ = 1.

#### 2.2.5.3 Total solar energy transmittance of the glazing and window

To obtain the total solar energy transmittance of the glazing of each window i, $g_{gl,i}$, the total solar energy transmittance of the glazing for the normal angle of incidence, $g_{gl,n,i}$, must be multiplied by a correction factor, $F_W$=0.9. This correction factor takes into account the fact that the time-averaged total solar energy transmittance value is somewhat lower than $g_{gl,n,i}$:

$$g_{gl,i} = g_{gl,n,i} \times F_W [-] \quad (25)$$

The same is valid for the total solar energy transmittance of the window i, $g_{w,i}$:

$$g_{w,i} = g_{w,n,i} \times F_W [-] \quad (26)$$

#### 2.2.5.4 Total solar energy transmittance of the glazing and window with the shading device in use

The total solar energy transmittance of the glazing with the shading device in use and total solar energy transmittance of the window with the shading in use are obtained according to:

$$g_{gl,sh,i} = g_{gl,i} \times SSC_i \ [-] \quad (27)$$

$$g_{w,sh,i} = g_{w,i} \times SSC_i \ [-] \quad (28)$$

where:

$g_{gl,i}$ is the total solar energy transmittance of the glazing of each window i, when the solar shading device is not in use, determined in accordance with 2.2.5.3;

$g_{gl,sh,i}$ is the total solar energy transmittance of the glazing of each window i, when the solar shading device is in use, determined in accordance with 2.2.5.3;

$g_{w,i}$ is the total solar energy transmittance of the window i when the solar shading device is not in use, determined in accordance with 2.2.5.3;

$g_{w,sh,i}$ is the total solar energy transmittance of the window i when the solar shading device is in use, determined in accordance with 11.4.2;

$SSC_i$ is the solar shading coefficient of the solar shading device defined for the window i.

### 2.2.6 Total solar radiation on each window

Based on the hourly values over the year of the total solar radiation per square meter of vertical surfaces of eight different orientations (North, North/East, East, South/East, South, South/West, West, North/West), calculated with BuildingCalc/LightCalc (BYG.DTU, 2007), the monthly average of the daily total solar radiation per square meter of vertical surfaces was calculated for the eight orientations according to:

$$I_{sol,k,day,m} = \frac{\sum_{h=1}^{h=n} I_{sol,k,h,m}}{l_m} \ [Wh/m^2] \quad (29)$$

where:

$I_{sol,k,day,m}$ is the monthly average (for the month m) of the total radiation over one day on a vertical surface with orientation k in $Wh/m^2$;

$I_{sol,k,h,m}$ is the total solar radiation over the hour h of the month m on a vertical surface with orientation k in $Wh/m^2$;

$l_m$ is the number of days of the month m;

$n$ is the number of hours of the month m.

<u>Note 1:</u> The results from this calculation are presented in the hidden Worksheet "DRY-Month" in the program.

<u>Note 2:</u> Only data for vertical surfaces is implemented in the program, and therefore only vertical windows may be defined.

For each window i, with a given orientation, the average daily total solar radiation for each month m, $I_{sol,i,day,m}$, is calculated by linear interpolation of the pre-calculated values $I_{sol,k,day,m}$.

After calculating the lengths of the heating and cooling seasons (in accordance with 2.2.11.1 and 2.2.11.2), the total solar radiation per square meter of each window may be calculated over the heating and cooling seasons according to:

$$I_{sol,i,HS} = \frac{\sum_{m=1}^{m=12} l_{m,HS} I_{sol,i,day,m}}{1000} \; [kWh/m^2] \qquad (30)$$

$$I_{sol,i,CS} = \frac{\sum_{m=1}^{m=12} l_{m,CS} I_{sol,i,day,m}}{1000} \; [kWh/m^2] \qquad (31)$$

$I_{sol,i,HS}$ is the total solar radiation per square metre of the window i area, with a given orientation and tilt angle, over the heating season, in $kWh/m^2$;

$I_{sol,i,CS}$ is the total solar radiation per square metre of the window i area, with a given orientation and tilt angle, over the cooling season, in $kWh/m^2$;

$I_{sol,i,day,m}$ is the monthly average (for the month m) of the daily total solar radiation per square metre of the window i area, with a given orientation and tilt angle, in $Wh/m^2$;

$l_{m,HS}$ is the number of days of the month m belonging to the heating season;

$l_{m,CS}$ is the number of days of the month m belonging to the cooling season.

### 2.2.7 Number of degree-hours during the heating season and cooling seasons

After the lengths of the heating and cooling seasons have been determined (in accordance with 2.2.11.1 and 2.2.11.2), the number of degree-hours during the heating season, $G_{HS}$, and the number of degree-hours during the cooling season, $G_{CS}$, are calculated according to:

$$G_{HS} = \frac{\sum_{m=1}^{m=12} 24 \times l_{m,HS}(\theta_{i,set,H} - \theta_{e,m})}{1000} \; [kKh] \qquad (32)$$

$$G_{CS} = \frac{\sum_{m=1}^{m=12} 24 \times l_{m,CS}(\theta_{i,set,C} - \theta_{e,m})}{1000} \; [kKh] \qquad (33)$$

where:

$\theta_{i,set,H}$ is the setpoint temperature for heating defined by the user, expressed in $°C$;

$\theta_{i,set,C}$ is the setpoint temperature for cooling defined by the user, expressed in $°C$;

$\theta_{e,m}$ is the monthly average of the daily external air temperature for the month m, expressed in $°C$. It was calculated using the Design Reference Year, Jensen J.M. and Lund H.(1995). The results are presented in the hidden Worksheet "DRY - Month" in the program;

$l_{m,HS}$ is the number of days of the month m belonging to the heating season;

$l_{m,CS}$ is the number of days of the month m belonging to the cooling season.

### 2.2.8 Dimensionless utilization factors for the heating and cooling seasons

#### 2.2.8.1 Dimensionless utilization factor for the solar gains during the heating season

The dimensionless gain utilization factor for heating season, $\eta_{HS,gn}$, is a function of the heat-balance ratio for the heating season, $\gamma_H$, and a numerical parameter, $a_H$, that depends on the dwelling inertia. $\eta_{HS,gn}$ is calculated according to the Equations (34) to (37):

$$if\ \gamma_H > 0\ and\ \gamma_H \neq 1: \qquad \eta_{HS,gn} = \frac{1-\gamma_H{}^{a_H}}{1-\gamma_H{}^{a_H+1}} \qquad (34)$$

$$if\ \gamma_H = 1: \qquad \eta_{HS,gn} = \frac{a_H}{a_H+1} \qquad (35)$$

$$if\ \gamma_H < 0: \qquad \eta_{HS,gn} = 1/\gamma_H \qquad (36)$$

with

$$\gamma_H = \frac{Q_{HS,gn}}{Q_{HS,ht}} \qquad (37)$$

where:

$\gamma_H$ is the dimensionless heat-balance ratio for the heating season;

$Q_{HS,ht}$ is the total heat transfer of the dwelling by transmission and ventilation during the heating season in $kWh$, determined in accordance with 2.2.9.1;

$Q_{HS,gn}$ represents the total heat gains of the dwelling during the heating season in $kWh$, determined in accordance with 2.2.9.2;

$a_H$ is a dimensionless numerical parameter depending on the time constant, $\tau_H$, defined by:

$$a_H = a_{H,0} + \frac{\tau}{\tau_{H,0}} \qquad (38)$$

where:

$a_{H,0}$ is a dimensionless reference numerical parameter, that takes the value 0.8 for the seasonal calculation method;

$\tau$ is the time constant of the dwelling in hours, determined in accordance with 2.2.8.3;

$\tau_{H,0}$ is a reference time constant that takes the value 30 hours for the seasonal calculation method.

### 2.2.8.2 Dimensionless utilization factor for the heat losses during the cooling season

The dimensionless loss utilization factor for cooling season, $\eta_{CS,ls}$, is a function of the heat-balance ratio for the cooling season, $\gamma_C$, and a numerical parameter, $a_C$, that depends on the dwelling inertia. $\eta_{ls,CS}$ is calculated according to the Equations (39) to (42):

$$if\ \gamma_C > 0\ and\ \gamma_C \neq 1: \qquad \eta_{CS,ls} = \frac{1-\gamma_C{}^{-a_C}}{1-\gamma_C{}^{-(a_C+1)}} \qquad (39)$$

$$if\ \gamma_C = 1: \qquad \eta_{CS,ls} = \frac{a_C}{a_C+1} \qquad (40)$$

$$if\ \gamma_C < 0: \qquad \eta_{CS,ls} = 1 \qquad (41)$$

with

$$\gamma_C = \frac{Q_{CS,gn}}{Q_{CS,ht}} \qquad (42)$$

where:

$\gamma_C$ is the dimensionless heat-balance ratio for the cooling season;

$Q_{CS,ht}$ is the total heat transfer of the dwelling by transmission and ventilation for the cooling season in $kWh$, determined in accordance with 2.2.9.1;

$Q_{CS,gn}$ represents the total heat gains of the dwelling for the cooling season in $kWh$, determined in accordance with 2.2.9.2;

$a_C$ is a dimensionless numerical parameter depending on the time constant, $\tau_C$, defined by:

$$a_C = a_{C,0} + \frac{\tau}{\tau_{C,0}} \qquad (43)$$

where:

$a_{C,0}$ is a dimensionless reference numerical parameter, that takes the value 0.8 for the seasonal calculation method;

$\tau$ is the time constant of the dwelling in hours, determined in accordance with 2.2.8.3;

$\tau_{H,0}$ is a reference time constant that takes the value 30 hours for the seasonal calculation method.

### 2.2.8.3 Dwelling time constant

The time constant of the dwelling, $\tau$, expressed in hours, characterizes the internal thermal inertia of the dwelling for both the heating and cooling seasons. It is calculated by:

$$\tau = \frac{C_m/3600}{H_{tr,adj}+H_{ve,adj}} \ [-] \qquad (44)$$

where

$C_m$ is the internal heat capacity of the dwelling, calculated in accordance with 2.2.8.4, in $J/K$;

$H_{tr,adj}$ is the heat transfer coefficient of the dwelling by transmission, calculated in accordance with 2.2.9.3, in $W/K$;

$H_{ve,adj}$ is heat transfer coefficient of the dwelling by ventilation, calculated in accordance with 2.2.9.4, in $W/K$;

<u>Note:</u> If $H_{ve,adj}$ for the heating season is different from $H_{ve,adj}$ for the cooling season, two different values of $\tau$ are obtained (one for the heating season and other for the cooling season).

#### 2.2.8.4 Internal thermal capacity of the dwelling

The internal thermal capacity of the dwelling, $C_m$, is selected from Tabel 3, in which the thermal capacity is presented for five different classes of buildings. $C_m$depends on $A_f$ that is the floor area of the dwelling expressed in $m^2$.

*Tabel 3 Values for the internal thermal capacity of the dwelling, $C_m$ (from CEN(2008, ISO 13790))*

| Class[a] | Monthly and seasonal method $C_m$ J/K[b] |
|---|---|
| Very light | 80 000 × $A_f$ |
| Light | 110 000 × $A_f$ |
| Medium | 165 000 × $A_f$ |
| Heavy | 260 000 × $A_f$ |
| Very heavy | 370 000 × $A_f$ |

### 2.2.9 Total heat transfer and heat gains of the dwelling during the heating and cooling seasons

#### 2.2.9.1 Total heat transfer of the dwelling during the heating and cooling seasons

The total heat transfer of the dwelling for the heating and cooling seasons is obtained according to:

$$Q_{HS,ht} = (H_{tr,adj} + H_{ve,adj}) \times G_{HS} \ [kWh] \quad (45)$$

$$Q_{CS,ht} = (H_{tr,adj} + H_{ve,adj}) \times G_{CS} \ [kWh] \quad (46)$$

where:

$H_{tr,adj}$ is the heat transfer coefficient of the dwelling by transmission, determined in accordance with 2.2.9.3, expressed in $W/K$;

$H_{ve,adj}$ is the heat transfer coefficient of the dwelling by ventilation, determined in accordance with 2.2.9.4, expressed in $W/K$;

$G_{HS}$ is the number of degree-hours during the heating season, calculated in accordance with 2.2.7, expressed in $kKh$;

$G_{CS}$ is the number of degree-hours during the cooling season in kKh, calculated in accordance with 2.2.7, expressed in $kKh$;

#### 2.2.9.2 Total heat heat gains of the dwelling during the heating and cooling seasons

The total heat gains, $Q_{gn}$, of the dwelling for the heating and cooling season are calculated according to:

$$Q_{HS,gn} = \sum_{m=1}^{m=12} l_{m,HS}\left(Q_{int,day} + Q_{sol,day,m}\right) \quad [kWh] \qquad (47)$$

$$Q_{CS,gn} = \sum_{m=1}^{m=12} l_{m,CS}\left(Q_{int,day} + Q_{sol,day,m}\right) \quad [kWh] \qquad (48)$$

where:

$Q_{int,day}$ is the sum of internal heat gains over one day, determined in accordance with 2.2.9.5, expressed in $kWh$;

$Q_{sol,day,m}$ is the monthly average (for the month m) of the of the daily solar heat gains, determined in accordance with 2.2.9.6, expressed in $kWh$;

$l_{m,HS}$ is the number of days of the month m that belong to the heating season;

$l_{m,CS}$ is the number of days of the month m that belong to the cooling season.

#### 2.2.9.3 Heat transfer coefficient of the dwelling by transmission

The heat transfer coefficient of the dwelling by transmission, $H_{tr,adj}$ is calculated according to:

$$H_{tr,adj} = H_{tr,w} + H_{tr,op} \quad [W/K] \qquad (49)$$

where:

$H_{tr,w}$ is the total heat transfer coefficient of the windows of the dwelling, $\sum_i U_{w,i}\, A_{w,i}$, in $W/K$;

$H_{tr,op}$ is the total heat transfer coefficient of the opaque elements of the dwelling, $UA$-*value* of the dwelling, given by the user, in $W/K$. It includes heat losses through the opaque elements of the dwelling envelope as well as linear thermal losses.

<u>Note:</u> Heat transfer by transmission through unconditioned spaces or adjacent buildings is not taken into account.

#### 2.2.9.4 Heat transfer coefficient of the dwelling by ventilation

The heat transfer coefficient of the dwelling by ventilation, $H_{ve,adj}$, is calculated according to:

$$H_{ve,adj} = \rho_a c_a (q_{ve} + q_{\inf}) \quad [W/K] \qquad (50)$$

where:

$\rho_a c_a$ is the heat capacity of air per volume, expressed in $(J/m^3K)$ and equal to $1200\ J/(m^3K)$;

$q_{ve}$ is the time-average air flow rate by natural or mechanical ventilation, expressed in $m^3/s$.

$q_{inf}$ is the time-average air flow rate by infiltration, expressed in $m^3/s$.

In case that heat recovery unit exists, $H_{ve,adj}$, is calculated according to:

$$H_{ve,adj} = \rho_a c_a \left[(1 - f_{ve,frac} \times \eta_{hru}) q_{ve} + q_{\inf}\right]\ [W/K] \qquad (51)$$

where:

$\rho_a c_a$ is the heat capacity of air per volume, expressed in $(J/m^3K)$ and equal to $1200\ J/(m^3K)$;

$q_{ve}$ is the time-average air flow rate by mechanical ventilation, expressed in $m^3/s$.

$q_{inf}$ is the time-average air flow rate by infiltration, expressed in $m^3/s$.

$f_{ve,frac}$ is the fraction of the air flow rate by ventilation that goes through the heat recovery unit, assumed to be equal to 1;

$\eta_{hru}$ is the efficiency of the heat recovery unit.

<u>Note:</u> the heat recovery unit can be activated during the heating season and bypassed during the cooling season which leads to different heat transfer coefficients by ventilation for the heating and cooling seasons.

#### 2.2.9.5 Daily internal gains of the dwelling

The daily internal gains of the dwelling are calculated according to:

$$Q_{int,day} = \frac{\phi_{int} \times t_{day}}{1000} \quad [kWh] \qquad (52)$$

where:

$\phi_{int}$ is the heat flow rate of the internal heat sources in W;

$t_{day}$ is the number of hours per day, that is 24 hours.

#### 2.2.9.6 Monthly average of the daily solar gains of the dwelling

The monthly average of the daily solar gains, $Q_{sol,day,m}$, is calculated according to:

$$Q_{sol,day,m} = \left(\sum_i F_{sh,ob,i,m}\ A_{sol,i,m}\ I_{sol,i,day,m}\right)/1000\ \ [kWh] \qquad (53)$$

where:

$F_{sh,ob,i,m}$ is the shading reduction factor for external obstacles for each window i for the month m, calculated in accordance with 2.2.4;

$A_{sol,i,m}$ effective solar collecting area of each window i for each month m, in $m^2$, calculated in accordance with 2.2.5;

$I_{sol,i,day,m}$ is the monthly average (for the month m) of the daily total solar radiation on each window i, with a given orientation, calculated in accordance with 2.2.6, expressed in $Wh/m^2$.

Note: the solar gains through opaque elements of the dwelling envelope are ignored.

### 2.2.10 Seasonal dwelling energy consumption

#### 2.2.10.1 Dwelling energy consumption during the heating season

For the dwelling, the energy need for space heating during the heating season, $Q_{nd,HS}$, is calculated according to:

$$Q_{HS,nd} = \frac{Q_{HS,ht} - \eta_{HS,gn} \times Q_{HS,gn}}{A_f}\ [kWh/m^2] \qquad (54)$$

where:

$Q_{HS,ht}$ is the total heat transfer of the dwelling for the heating season, determined in accordance with 2.2.9.1, expressed in $kWh$;

$Q_{HS,gn}$ is the total heat gains of the dwelling for the heating season, determined in accordance with 2.2.9.2, expressed in $kWh$;

$\eta_{HS,gn}$ is the dimensionless gain utilization factor for the solar gains during the heating season, determined in accordance with 2.2.8.1;

$A_f$ is the floor area of the dwelling in $m^2$.

#### 2.2.10.2 Dwelling energy consumption during the cooling season

For the dwelling, the energy need for space cooling during the cooling season, $Q_{C,nd}$, is calculated according to:

$$Q_{CS,nd} = \frac{Q_{CS,gn} - \eta_{CS,ls} \times Q_{CS,ht}}{A_f} [kWh/m^2] \qquad (55)$$

where:

$Q_{CS,ht}$ is the total heat transfer of the dwelling for the cooling season, determined in accordance with 2.2.9.1, expressed in $kWh$;

$Q_{CS,gn}$ is the total heat gains of the dwelling for the cooling season, determined in accordance with 2.2.9.2, expressed in $kWh$;

$\eta_{C,ls}$ is the dimensionless gain utilization factor for the solar gains during the cooling season, determined in accordance with 2.2.8.2;

$A_f$ is the floor area of the dwelling in $m^2$.

### 2.2.11 Length of the heating and cooling seasons

#### 2.2.11.1 Length of the heating season

The length of the heating season, $l_{HS}$ is defined by the following equation, which means that the heating season includes all days for which the heat gains, calculated with a conventional utilization factor, $\eta_{HS,gn,1}$, do not balance the heat transfer:

$$\theta_{e,day} \leq \theta_{i,set,H,day} - \frac{\eta_{HS,gn,1} Q_{gn,day}}{(H_{tr,adj} + H_{ve,adj}) t_{day}} \qquad (56)$$

where

$\theta_{e,day}$ is the daily average external temperature, expressed in $°C$ (from the Design Reference Year (Jensen J.M. and Lund H., 1995));

$\theta_{i,set,H,day}$ is the set-point temperature for heating in $°C$;

$\eta_{H,gn,1}$ is the conventional gain utilization factor calculated with $\gamma_H = 1$, calculated in accordance with 2.2.8.1;

$Q_{gn,day}$ is the daily average internal and solar gains in $kWh$, calculated in accordance with 2.2.9.6;

$H_{tr,adj}$ is the heat transfer coefficient by transmission in $W/K$, calculated in accordance with 2.2.9.3;

$H_{ve,adj}$ is the heat transfer coefficient by ventilation in $W/K$, calculated in accordance with 2.2.9.4;

$t_{day}$ is the duration of the day, that is 24 h.

The monthly average values of daily temperatures and heat gains are attributed to the 15th day of each month. Linear interpolation is used to obtain the limiting days for which Equation (45) is verified.

#### 2.2.11.2 Length of the cooling season

The length of the cooling season, $l_{CS}$ is obtained in a similar way to the length of the heating season. The cooling season includes all the days for which the (positive) heat transfer, calculated with a conventional utilization factor, $\eta_{C,ls,1}$, do not balance the heat gains:

$$\theta_{e,day} \geq \theta_{i,set,C,day} - \frac{Q_{gn,day}}{\eta_{C,ls,1}(H_{tr,adj}+H_{ve,adj})t_{day}} \qquad (57)$$

where

$\theta_{e,day}$ is the daily average external temperature, expressed in $°C$(from the Design Reference Year (Jensen J.M. and Lund H., 1995));

$\theta_{i,set,C,day}$ is the set-point temperature for cooling in $°C$;

$\eta_{C,ls,1}$ is the conventional gain utilization factor calculated with $1/\gamma_C = 1$, in accordance with 2.2.8.2;

$Q_{gn,day}$ is the daily average internal and solar gains in $MJ$, calculated in accordance with 2.2.9.2;

$H_{tr,adj}$ is the heat transfer coefficient by transmission in $W/K$, calculated in accordance with 2.2.9.3;

$H_{ve,adj}$ is the heat transfer coefficient by ventilation in $W/K$; calculated in accordance with 2.2.9.3;

$t_{day}$ is the duration of the day, that is 24 h.

The monthly average values of daily temperatures and heat gains are attributed to the 15th day of each month. Linear interpolation is used to obtain the limiting days for which Equation (46) is verified.

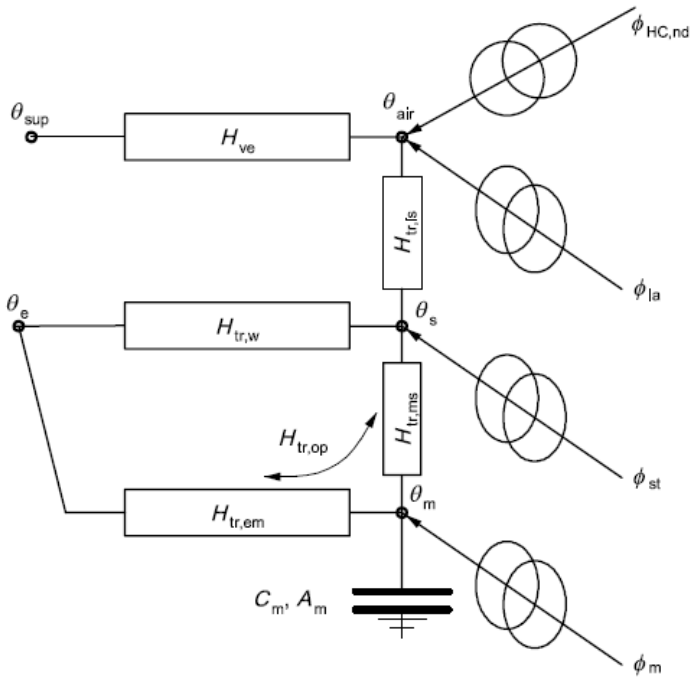
## 2.3 STEP 3 - Energy consumption and indoor comfort temperature of a room of the dwelling - Hourly calculation

### 2.3.1 The Goal

In Step 3, the purpose is to perform a hourly calculation for a critical room (thermal zone) of the dwelling in order to identify possible situations of overheating. The method used is the *simple hourly method* described in CEN(2008, ISO 13790).

### 2.3.2 The model used in the *simple hourly method* described in CEN(2008, ISO 13790)

The *simple hourly method* described in CEN(2008, ISO 13790) is based on the following five resistances, one capacitance (5R1C) model:




*Figur 22 Five resistances, one capacitance (5R1C) model described in CEN(2008, ISO 13790)*

where:

$\theta_{air}$ is the node representing the internal air temperature

$\theta_s$ is the central node (a mix of $\theta_{air}$ and mean radiant temperature)

$\theta_m$ is the node representing the mass of the room (thermal zone)

$H_{ve}$ is the heat transfer coefficient by ventilation

$\theta_{sup}$ is the node representing the supply air temperature by ventilation

$H_{tr,w}$ is the heat transfer coefficient by transmission for windows and doors

$H_{tr,op}$ is the heat transfer coefficient by transmission for opaque elements (split into $H_{tr,em}$ and $H_{tr,ms}$)

$H_{tr,is}$ is the coupling conductance between the internal air node $\theta_{air}$ and the central node $\theta_s$

$\theta_e$ is the node representing the external air temperature

$\phi_{ia}$, $\phi_{st}$ and $\phi_m$ represent the heat flow rates from internal heat sources $\phi_{int}$ and solar gains $\phi_{sol}$

$C_m$ is the internal heat capacity and $A_m$ the effective mass area of the room

$\phi_{HC,nd}$ represents the heating or cooling need

### 2.3.3 External air temperature, $\theta_e$

The hourly external air temperature was obtained from the Design Reference Year (Jensen J.M. and Lund H.,1995).

### 2.3.4 Coupling conductance between nodes $\theta_{air}$ and $\theta_s$, $H_{tr,is}$

The coupling conductance, $H_{tr,is}$, expressed in $W/K$, between the air node, $\theta_{air}$, and the surface node, $\theta_s$, is given by the following equation:

$$H_{tr,is} = h_{is} A_{tot} \; [W/K] \qquad (58)$$

where:

$h_{is}$ is the heat transfer coefficient between the air node, $\theta_{air}$, and the surface node, $\theta_s$, with a fixed value of $h_{is} = 3.45 \; W/m^2K$;

$A_{tot}$ is the area of all surfaces facing the building zone, equal to $A_{at} \times A_f$ expressed in $m^2$;

$A_f$ is the floor area expressed in $m^2$;

$A_{at}$ is the dimensionless ratio between the internal surfaces area and the floor area; $A_{at}$ is assumed to be equal to 4.5.

### 2.3.5 Coupling conductance between nodes $\theta_m$ and $\theta_s$, $H_{tr,ms}$

The coupling conductance, $H_{tr,ms}$, expressed in $W/K$, between the air node, $\theta_m$, and the surface node, $\theta_s$, is given by the following equation:

$$H_{tr,ms} = h_{ms} A_m \; [W/K] \qquad (59)$$

where:

$h_{ms}$ is the heat transfer coefficient between the nodes $\theta_m$ and $\theta_s$, with a fixed value of $h_{ms} = 9.1 W/m^2K$;

$A_m$ is the effective mass area obtained from 2.3.13, expressed in $m^2$;

### 2.3.6 Split of the transmission heat transfer coefficient for opaque elements $H_{tr,op}$ into $H_{tr,em}$ and $H_{tr,ms}$

The split of the transmission heat transfer coefficient for opaque elements $H_{tr,op}$ into $H_{tr,em}$ and $H_{tr,ms}$ is calculated according to:

$$H_{tr,em} = \frac{1}{1/H_{tr,op} - 1/H_{tr,ms}} \; [W/K] \qquad (60)$$

where:

$H_{tr,op}$ is the heat transfer coefficient of the opaque elements of the room envelope, in $W/K$

$H_{tr,ms}$ is the coupling conductance, obtained from 2.3.5, expressed in $W/K$.

### 2.3.7 Heat transfer coefficient by transmission through opaque elements of the room envelope

The heat transfer coefficient of the opaque elements of the room envelope, $H_{tr,op}$, is the *UA-value* of the room in $W/K$ given by the user. It includes heat losses through the opaque elements of the room envelope as well as linear thermal losses.

### 2.3.8 Heat transfer coefficient by transmission through windows and doors of the room envelope

The heat transfer coefficient of the windows and doors of the room envelope, $H_{tr,w}$ is calculated according to:

$$H_{tr,w} = \sum_i U_{w,i} A_{w,i} \; [W/K] \qquad (61)$$

where:

$U_{w,i}$ is the thermal transmittance coefficient of each window i of the room in $W/m^2K$

$A_{w,i}$ is the area of each window i of the room in $m^2$

### 2.3.9 Heat transfer coefficient by ventilation

The heat transfer coefficient of the dwelling by ventilation, $H_{ve,adj}$, is calculated according to:

$$H_{ve,adj} = \rho_a c_a (q_{ve} + q_{\inf}) \quad [W/K] \qquad (62)$$

where:

$\rho_a c_a$ is the heat capacity of air per volume, expressed in $(J/m^3K)$ and equal to $1200\ J/(m^3K)$;

$q_{ve}$ is the air flow rate by natural or mechanical ventilation, expressed in $m^3/s$.

$q_{inf}$ is the air flow rate by infiltration, expressed in $m^3/s$.

In case that heat recovery unit exists, when it is activated, $H_{ve,adj}$, is calculated according to:

$$H_{ve,adj} = \rho_a c_a \left[(1 - f_{ve,frac} \times \eta_{hru}) q_{ve} + q_{\inf}\right] \ [W/K] \qquad (63)$$

where:

$\rho_a c_a$ is the heat capacity of air per volume, expressed in $(J/m^3K)$ and equal to $1200\ J/(m^3K)$;

$q_{ve}$ is the air flow rate by mechanical ventilation, expressed in $m^3/s$.

$q_{inf}$ is the air flow rate by infiltration, expressed in $m^3/s$.

$f_{ve,frac}$ is the fraction of the air flow rate by ventilation that goes through the heat recovery unit, assumed to be equal to 1;

$\eta_{hru}$ is the efficiency of the heat recovery unit.

In case that venting is available, when it is activated, $H_{ve,adj}$, is calculated according to:

$$H_{ve,adj} = \rho_a c_a (q_{venting}) \quad [W/K] \qquad (64)$$

where:

$\rho_a c_a$ is the heat capacity of air per volume, expressed in $(J/m^3K)$ and equal to $1200\ J/(m^3K)$;

$q_{venting}$ is the air flow rate by venting, expressed in $m^3/s$.

Note1: In case that heat recovery unit exists, it is controlled every hour t according to:

1. The internal air temperature is calculated for the hour t without the use of the heat recovery unit.
2. If the calculated internal air temperature is lower than $\theta_{air,set,H} + 2$ °C then the heat recovery unit is activated for that hour t.
3. The new internal air temperature is calculated for the hour t with the heat recovery unit active.

Note2: In case that venting is available, it is controlled every hour t in the following way:

1. The internal air temperature is calculated for the hour t without venting.
2. If the calculated internal air temperature is higher than the venting setpoint temperature, then venting is activated for the hour t.
3. The new internal air temperature is calculated for the hour t with venting.

### 2.3.10 Heat flow from internal and solar heat sources

The heat flow rates from internal and solar heat sources $\phi_{int}$ and $\phi_{sol}$, expressed in $W$, are split between the air node, $\theta_{air}$, and the internal nodes, $\theta_s$, $\theta_m$, according to:

$$\phi_{ia} = 0.5\phi_{int} \quad [W] \tag{65}$$

$$\phi_m = \frac{A_m}{A_{tot}}\left(0.5\phi_{int} + \phi_{sol}\right) \quad [W] \tag{66}$$

$$\phi_{st} = \left(1 - \frac{A_m}{A_{tot}} - \frac{H_{tr,w}}{9.1A_{tot}}\right)\left(0.5\phi_{int} + \phi_{sol}\right) \quad [W] \tag{67}$$

where:

$\phi_{int}$ is the heat flow from internal sources, calculated according to 2.3.11, expressed in $W$

$\phi_{sol}$ is the heat flow from solar heat source, calculated according to 2.3.12, expressed in $W$

$A_{tot}$ is the area of all surfaces facing the building zone, calculated in accordance with 2.3.3, expressed in $m^2$;

$A_m$ is the effective mass area, calculated according to 2.3.13, expressed in $m^2$

### 2.3.11 Heat flow from internal sources

The heat flow from internal sources, $\phi_{int}$, in $W$, is assumed to be constant for every hour of the year.

### 2.3.12 Heat flow from solar heat source

For every hour, the heat flow rate from solar heat source, $\phi_{sol}$, in $W$, is calculated according to:

$$\phi_{sol} = \sum_i F_{sh,ob,i} A_{sol,i} \cdot I_{sol,i} \quad [W] \qquad (68)$$

where:

$F_{sh,ob,i}$ is the shading reduction factor due to external obstacles for the window i for every hour (no units);

$A_{sol,i}$ is the effective collecting area of the window i with a given orientation and tilt angle for every hour in $m^2$, calculated in accordance with 2.3.12.1. It takes into the total solar energy transmittance of the window and the reduction factor of movable shading devices;

$I_{sol,i}$ is the solar radiation per square meter of window i surface for every hour, in $W/m^2$

Note: Solar gains from opaque elements are ignored.

The shadings from horizon, overhang and fins were also ignored for the hourly calculation due to unclear information in the CEN(2008, ISO 13790). In this way $F_{sh,ob,i}$ is equal to 1.

#### 2.3.12.1 Effective collecting area of the window i

For every hour, the effective collecting area of each window i, $A_{sol,i}$, is calculated according to:

$$A_{sol,i} = g_{gl,i}(1 - F_{F,i}) A_{w,i} \; [m^2] \qquad (69)$$

where:

$g_{gl,i}$ is the total solar energy transmittance of the glazing for each window i, determined in accordance with 2.2.5.3. For every hour in which $I_{sol,i}$>300 $W/m^2$, $g_{gl+sh,i}$ which is total solar energy transmittance of the glazing with the shading device in use for each window i, calculated according to 2.2.5.3.

$F_{F,i}$ is the frame area fraction of each window i, ratio of the frame area to the overall window area (no units);

$A_{w,i}$ is the window i area in , expressed in $m^2$.

Note: If the window i was defined by $A_w$, $U_w$ and $g_w$ and if there is no information about $g_{gl}$ and $F_F$, the Equation (70) is used in the following way:

$$A_{sol,i,j} = g_{w,i} A_{w,i} \; [m^2] \qquad (70)$$

where:

$g_{w,i}$ is the total solar energy transmittance of the window i, determined in accordance with 2.2.5.3. For every hour in which $I_{sol,i}$>300 $W/m^2$, $g_{w+sh,i}$ which is total solar energy transmittance of the window i with the shading device in use, calculated according to 2.2.5.3.

#### 2.3.12.2 Solar radiation per square meter of window i surface

Based on the hourly values of the total solar radiation per square meter of vertical surfaces of eight different orientations (North, North/East, East, South/East, South, South/West, West, North/West – calculated with BuildingCalc/LightCalc - BYG.DTU (2007) - hidden Worksheet "DRY-Hourly"), the total solar radiation can be calculated for each window i with a given orientation by linear interpolation.

Note 1: As referred for Step 2, only data for vertical surfaces is implemented in the program, and therefore only vertical windows may be defined.

### 2.3.13 Values for dynamic parameters, $C_m$ and $A_m$

The internal thermal capacity of the room, $C_m$, and the effective mass area, $A_m$, are given in Tabel 4 for five different classes of buildings. $C_m$and $A_m$depend on $A_f$ that is the floor area of the room (thermal zone).

*Tabel 4 Values for the dynamic parameters of the room, $A_m$ and $C_m$(from CEN(2008, ISO 13790))*

| Class[a] | Simple hourly method | |
|---|---|---|
| | $A_m$ m$^2$ | $C_m$ J/K |
| Very light | 2,5 × $A_f$ | 80 000 × $A_f$ |
| Light | 2,5 × $A_f$ | 110 000 × $A_f$ |
| Medium | 2,5 × $A_f$ | 165 000 × $A_f$ |
| Heavy | 3,0 × $A_f$ | 260 000 × $A_f$ |
| Very heavy | 3,5 × $A_f$ | 370 000 × $A_f$ |

### 2.3.14 Air temperature for a given value of $\phi_{HC,nd}$

The solution for the model, according to CEN(2008, ISO 13790), is given for a considered time step of one hour according to the following equations. The temperatures are an average over one hour except for $\theta_{m,t}$ and $\theta_{m,t-1}$ which are instantaneous values at time $t$ and $t-1$.

For a given time step, $\theta_{m,t}$, expressed in $°C$, is calculated at the end of the time step from the previous step $\theta_{m,t-1}$ by:

$$\theta_{m,t} = \frac{\theta_{m,t-1}\left[(C_m/3600) - 0.5(H_{tr,3} + H_{tr,em})\right] + \phi_{mtot}}{(C_m/3600) + 0.5(H_{tr,3} + H_{tr,em})} \ [°C] \tag{71}$$

with

$$\phi_{mtot} = \phi_m + H_{tr,em}\theta_e + H_{tr,3}\frac{\phi_{st} + H_{tr,w}\theta_e + H_{tr,1}\left[(\phi_{ia} + \phi_{HC,nd})/H_{ve} + \theta_{sup}\right]}{H_{tr,2}} \tag{72}$$

$$H_{tr,1} = \frac{1}{1/H_{ve} + 1/H_{tr,is}} \quad [W/K] \tag{73}$$

$$H_{tr,2} = H_{tr,1} + H_{tr,w} \quad [W/K] \tag{74}$$

$$H_{tr,3} = \frac{1}{1/H_{tr,2} + 1/H_{tr,ms}} \quad [W/K] \tag{75}$$

For the considered time step, the average values of nodes temperatures are given by:

$$\theta_m = (\theta_{m,t} + \theta_{m,t-1})/2 \ [°C] \tag{76}$$

$$\theta_s = \frac{H_{tr,ms}\theta_m + \phi_{st} + H_{tr,w}\theta_e + H_{tr,1}[\theta_{sup} + (\phi_{ia} + \phi_{HC,nd})/H_{ve}]}{H_{tr,ms} + H_{tr,w} + H_{tr,1}} \ [°C] \tag{77}$$

$$\theta_{air} = \frac{H_{tr,is}\theta_s + H_{ve}\theta_{sup} + \phi_{ia} + \phi_{HC,nd}}{H_{tr,is} + H_{ve}} \ [°C] \tag{78}$$

### 2.3.15 Hourly calculation of internal temperature and required heating and cooling need: sequence of calculations performed

For every hour t of the year (t=1 to t=8760) the following sequence of calculations is performed (see hidden Worksheet "STEP3_Calculation" in the program):

1. Calculation of the total solar radiation for each window i of the room according to 2.3.12.2;
2. Selection between $g_{gl,i}$ and $g_{gl+sh,i}$ depending on if the shading device is in use, according to 2.3.12.1.
3. Calculation of the effective collective area for each window i of the room according to 2.3.12.1.
4. The heat flow by solar gains is first calculated for each window i, $\phi_{sol,i}$ and afterwards for the total number of windows of the room $\phi_{sol}$, according to 2.3.12.
5. Knowing $\phi_{int}$ and $\phi_{sol}$, $\phi_m$ and $\phi_{st}$ are calculated according to 2.3.10.
6. A pre-calculation is performed to evaluate if there is need for the use of heat exchanger or venting, with $\phi_{HC,nd}$=0 and with $\theta_{sup} = \theta_e$.
   6.1 Calculation of $H_{ve}$ without taking into account the heat recovery unit or venting, according to 2.3.9 .
   6.2 Calculation of $H_{tr,1}$, $H_{tr,2}$ and $H_{tr,3}$ according to 2.3.14.
   6.3 Calculation of $\phi_{mtot}$ according to 2.3.14.
   6.4 Calculation of $\theta_{m,t}$ according to 2.3.14. For the first hour, t=1, $\theta_{m,t-1}$ is assumed to be $20°C$
   6.5 Calculation of $\theta_m$, $\theta_s$ and $\theta_{air}$ according to 2.3.14.
7. Check if there is need for the use of the heat recovery unit or venting:
   7.1 If $\theta_{air,0}$<$\theta_{air,set,H} + 2$ the heat exchanger is activated if available, which means that $H_{ve}$ is corrected to take into account the heat exchanger according to 2.3.9
   7.2 If $\theta_{air,0}$>$\theta_{air,set,venting}$ the venting is activated if available, which means that $H_{ve}$ is corrected to take into account the venting according to 2.3.9.
   7.3 If $\theta_{air,set,H} + 2 < \theta_{air,0} < \theta_{air,set,venting}$ or if there is no heat recovery unit or venting available, $H_{ve}$ keeps the value calculated in 6.1
   7.4 Steps 6.2 to 6.5 are repeated for the corrected $H_{ve}$.
8. Check if there is need for heating or cooling
   8.1 If $\theta_{air,0}$<$\theta_{air,set,H}$ then the internal air temperature is set to the heating setpoint temperature ($\theta_{air,set} = \theta_{air,set,H}$)
   8.2 If $\theta_{air,0}$>$\theta_{air,set,C}$ then the internal air temperature is set to the cooling setpoint temperature ($\theta_{air,set} = \theta_{air,set,C}$) if there is mechanical cooling available. If there is no mechanical cooling available $\theta_{air,set}$=$\theta_{air,0}$
9. Repeat steps 6.2 to 6.5 with the corrected $H_{ve}$ but for $\phi_{HC,nd} = 10A_f$ in which $A_f$ is the floor area of the room in $m^2$
10. Calculate the need for heating/cooling $\phi_{HC,nd}$ according to:

$$\phi_{\mathrm{HC,nd},un}=\phi_{\mathrm{HC,nd},10}\frac{\theta_{air,set}-\theta_{air,0}}{\theta_{air,10}-\theta_{air,0}}$$

$\phi_{\mathrm{HC,nd},un}$ is positive for heating and negative for cooling.

11. For the calculated $\phi_{\mathrm{HC,nd},un}$ and $\theta_{air,set}$ calculate the correspondent $\theta_s$, $\theta_m$ and $\theta_{m,t}$ using equations (76), (77) and (78). $\theta_{m,t}$ will be used in the next time step as $\theta_{m,t-1}$
12. Perform the steps previously described for the 8760hours of the year.
13. The yearly room energy needs for heating and cooling are obtained according to:

$$Q_{heating} = \sum_{t=1,if\ \phi_{HC,nd,un}>0}^{t=8760} \frac{\phi_{HC,nd,un,t}}{1000 \times A_f}\ [kWh/m^2]$$

$$Q_{heating} = \sum_{t=1,if\ \phi_{HC,nd,un}>0}^{t=8760} \frac{\phi_{HC,nd,un,t}}{1000 \times A_f}\ [kWh/m^2]$$

with $A_f$ the area of the room in $m^2$

14. The number of hours with overheating in the room per year, if there is no mechanical cooling available, are calculated according to:

number of hours with overheating = $\sum_{t=1,if\ \theta_{set}>\theta_{air,set,C}}^{t=8760} 1$

<u>Note:</u> In order to avoid a large size of the WinDesign.xlsm file, the hourly calculation rows are deleted from hour 3 to hour 8760 every time the file is saved. In this way, before performing an hourly calculation the user must activate the hourly calculation, so the 8760 rows in the excel worksheet are filled in.

## 2.4 STEP 4 - Economic evaluation - Cost of conserved energy

### 2.4.1 The Goal

In Step 4, the purpose is to perform an economic evaluation for the different scenarios of windows used in the dwelling. The concept used in the Cost of Conserved Energy.

### 2.4.2 Cost of conserved energy

For each scenario of windows defined in *Step2*, the cost of conserved energy, $CCE$, for the lifetime of the windows, is calculated and compared to the reference scenario according to the following equation:

$$CCE = \frac{I - I_{ref}}{E_{ref} - E} \cdot \frac{d}{1-(1+d)^{-n}} \; [DKK/kWh] \qquad (79)$$

where:

$I - I_{ref}$ represents the investment cost, defined as the difference between the total cost of the windows of the actual scenario and the total cost of the windows of the reference scenario , expressed in Danish kroner;

$E_{ref} - E$ represents the annual savings, expressed as the difference between the total energy consumption of the windows of the reference scenario and the energy consumption of the windows of the actual scenario, calculated on a seasonal basis (in Step2), expressed in $kWh$;

$n$ is the economic evaluation period taking into account the lifetime of the windows, expressed in years (usually 30 years);

$d$ is the net discount rate.

Note: The user can specify if there is mechanical cooling available in the dwelling. If there is not mechanical cooling available the annual savings are calculated in terms of energy consumption of the windows during only the heating season.

# 3 References

BYG.DTU (2007). BuildingCalc/LightCalc, Building simulation tool, Computer program, Department of Civil Engineering, Technical University of Denmark.

CEN (2008, ISO 13790). ISO 13790, Energy performance of buildings - Calculation of energy use for space heating and cooling.

Jensen J.M. and Lund H. (1995). Design Reference Year, DRY - a new Danish Reference Year (in Danish: et nyt dansk reference år), Department of Buildings and Energy, Technical University of Denmark, in Danish.

Nielsen T. R., Duer K. and Svendsen S. (2001). Energy performance of glazings and windows, Solar Energy, Vol. 69 (Suppl.) Nos. 1-6, 137-143.

SBi (2006). Be05, version 17.07.2006, SBi, Statens Byggeforskninginstitut, Hørsholm, Danmark.

**BILAG 1**

**8TH Nordic Symposium Building Physics**

**Paper**

# Tool for selection of windows in dwellings

# Tool for Selection of Windows in Dwellings

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***KEYWORDS:*** *windows, dwellings, energy performance, indoor climate, economic evaluation*

***SUMMARY:***
*The paper presents a new tool to be used by architects and engineers for an optimized selection of windows in dwellings. The tool has been developed using Microsoft Office Excel 2007 and VBA and aims to be user-friendly and flexible, so it can be suitable for different levels of user expertise.*
*The tool organizes the process of selecting windows in four different stages.*
*A first stage, in which the user is able to compare the energy performance of different individual windows (varying in configuration, size and component performances) using the concept of net energy gain.*
*In a second stage, the user may define a combination of windows to be used in a dwelling and calculate their energy use on a seasonal basis, taking into account the utilization factors of the solar gains and heat losses for the heating and cooling seasons respectively, according to (CEN, 2007, prEN ISO 13790).*
*The main purpose of the third stage is to evaluate the indoor environment of critical rooms of the dwelling in order to verify whether or not the windows solutions selected as having a good energy performance also allow fulfilling the indoor comfort requirements defined in( CEN, 2007, EN 15251). The method used is the simple hourly method defined in (CEN, 2007, prEN ISO 13790). In this stage the indoor temperature and the heating/cooling energy demand are calculated for every hour of the year for each critical room of the dwelling.*
*The fourth step consists of a simple economic evaluation for the combinations of windows previously selected, based on cost of conserved energy during the dwelling lifetime.*
*Based on the overview of the stages previously mentioned, the optimum windows solution can be selected for each specific dwelling. In this way, the full potential of optimizing the energy performance of dwellings by optimizing the selection of windows can be used in an easy way.*

## 1. Introduction

The increasing concern about energy related issues, i.e. lack of energy supply security and climate problems, is resulting in a requirement for more and more energy efficient buildings. In Denmark, Be06 is the program used to document that the building design fulfills the energy frame required by the building code. However, with this software, it is not easy to evaluate and compare the performance of different solutions of windows in buildings. Furthermore, with Be06, it is not possible to analyze the quality of the indoor climate and how the windows influence on it. There was, therefore, a need to develop a calculation tool to be used by architects and engineers in the early phase of residential buildings design, in order to select the most appropriate solutions of windows for each particular case, with regard to area, configuration, orientation, solar shading devices and energy performance of the

window components. This tool is to be used either when designing new dwellings/flats or when renovating existing ones.

A similar tool, Resfen (Mitchell R. et. al., 2005), had already been developed in the Lawrence Berkeley National Laboratory, also with the purpose of helping designers and constructors during the selection procedure of windows in residential buildings. Based on some input data, such as U-value, g-value and air-leakage rate of the windows and some other information about the building, Resfen is able to calculate, on an hourly basis, the relative energy and economic performances of the windows in comparison to an insulated wall without windows. If the user wants to compare two different solutions of windows, he must perform two independent simulations and compare the final results.

However, Resfen, is not able to perform indoor climate evaluations, which is one of the main differences when compared to the new tool in this paper. The new tool also allows the user to create windows by selecting the desired configuration and components (glazing, frame/sash, transoms, mullions and glazing bars) from pre-defined lists. As a consequence the U-value, g-value and net energy gain of each individual window are automatically calculated. The results are presented in tables, which makes it very easy to compare the performance of different individual windows and of different solutions of windows applied to a house.

# 2. The method and the calculation program

## 2.1 Overview

The tool presented in this paper has been developed with the purpose of helping architects and engineers in the process of selecting the optimal windows solution for residential buildings. It can be used during the design phase of new buildings or for the renovation of existing ones.

Built in Microsoft Office Excel 2007 and Visual Basic for Applications (VBA), the tool aims to be user-friendly and based on simple input data. At the same time, it is adapted to different expertise levels: for example the inexperienced user has the option of using pre-defined solutions and default suggestions, while the experienced user can have a very high level of flexibility.

The method/tool organizes the process of selecting windows in four different stages named as *Step1*, *Step 2*, *Step 3* and *Step 4*.

In *Step 1*, the user can evaluate and compare the energy performance of different individual windows based on the knowledge of their configurations, sizes and components (glazings and frames). This first evaluation is based on the concept of the net energy gain defined in (Nielsen T. R. et. al., 2001).

In the second step, picking from the windows previously characterized, different combinations of windows (orientations, windows types, number of windows, tilt angles, shadings from horizon, overhangs, fins and movable solar shading devices) can be defined for a specific dwelling/flat. These combinations of windows may differ regarding the windows components as well as the windows configurations, sizes and orientations depending on the flexibility of each particular design case. The final result of this stage is the energy use of different combinations of windows integrated in the house. The calculation is made on a seasonal basis (winter/summer) taking into account the gain and loss utilization factors for heating and cooling, respectively, according to (CEN, 2007, prEN ISO 13790).

The basis *Step 3* is the simple hourly method defined in (CEN, 2007, prEN ISO 13790). In this stage the indoor temperature and the heating/cooling energy demand are calculated on an hourly basis for each critical room of the dwelling. The main goal of this stage is to verify whether or not the windows solutions selected as having a good energy performance also allow fulfilling the indoor comfort requirements defined in (CEN, 2007, EN 15251).

The *Step 4* consists of an economic evaluation for the combinations of windows previously selected. In this stage, it is possible to calculate the cost of conserved energy when using the selected windows solutions, in comparison to a reference solution.

Based on the overview of the analyses made during the four steps, the user is, at this stage, able to select the windows solutions with the optimal performance in the actual dwelling/flat.

Furthermore, the user is not obligated to follow the four steps. The user may only use *Step 1* to have a very quick idea of the energy performance of different individual windows with regard to configuration, size and components. Or the user may use only *Step 2* in order to perform a seasonal calculation knowing previously the U-value and g-value of the windows that he wants to use. *Step 3* and *Step 4* are independent from each other but require *Step 2* to be previously performed.

In *Fig.1* a sketch with the overview of the method and calculation program is presented.

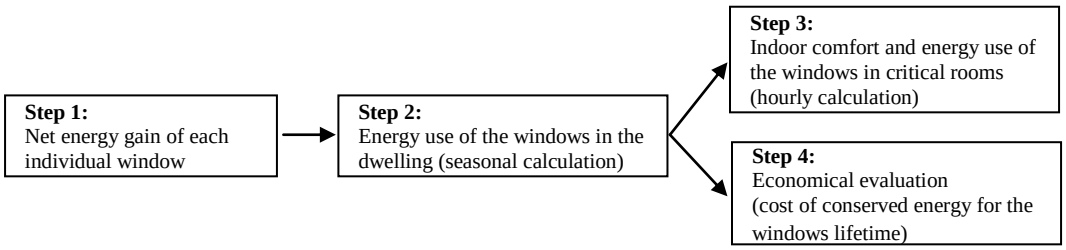


*FIG. 2 - Sketch with the overview of the method and calculation program.*

## 2.2 Step 1: Net energy gain of windows

### 2.2.1 The method

In this first step, the goal is to express, in an easy and simple way, the energy performance of different individual windows varying in configuration, dimension and components (glazing, frame, transoms, mullions and glazing bars). The concept used for this purpose is the net energy gain defined in (Nielsen T. R. et. al., 2001).

According to (Nielsen T. R. et. al., 2001), the net energy gain of a window is the difference between the solar gains and the heat losses that occur through that window during the heating season and it can be calculated for a reference house located in Denmark according to the following equation:

$$E_{ref} = I \cdot g_w - D \cdot U_w = 196.42 \cdot g_w - 90.36 \cdot U_w \; [kWh/m^2] \qquad (1)$$

in which $I = 194.42 kWh/m^2$ is the solar radiation calculated for the reference house during the heating season and $D = 90.36 kKh$ is the degree hour number during the heating season in Denmark. Both *I* and *D* are calculated using the Danish Reference Year (Jensen J.M. and Lund H., 1995)). $g_w$ and $U_w$ are, respectively, the total solar energy transmittance and the thermal transmittance of the window.

The net energy gain for the reference house indicates the energy performance of a window for an averaged orientation defined by the distribution of windows in the reference house (North 26%; South: 41% and East/West: 33%).

$g_w$ and $U_w$ are calculated according to equations *(2)* and *(3)*:

$$U_w = \frac{A_g \cdot U_g + A_f \cdot U_f + A_t \cdot U_t + A_m \cdot U_m + A_{gb} \cdot U_{gb} + l_{gf} \cdot \psi_{gf} + l_{gt} \cdot \psi_{gt} + l_{gm} \cdot \psi_{gm} + l_{ggb} \cdot \psi_{ggb}}{A_w} \; [W/m^2K] \qquad (2)$$

$$g_w = \frac{A_g \cdot g_g}{A_w} \; [-] \qquad (3)$$

where $A_w$ is the area of the window (in $m^2$), $A_g$ is the area of the glazing (in $m^2$), $A_f$ is the area of the frame/sash (in $m^2$), $A_t$ is the area of the transoms (in $m^2$), $A_m$ is the area of mullions in ($m^2$), $A_{gb}$ is the area of glazing bars (in $m^2$), $l_{gf}$ is the perimeter of the glazing along the frame (in $m$), $l_{gt}$ is the perimeter of the glazing along the transoms (in $m$), $l_{gm}$ is the perimeter of the glazing along the mullions (in $m$), $l_{ggb}$ is the perimeter of the glazing along the glazing bars, $U_g$ is the thermal transmittance of the glazing (in $W/m^2K$), $U_f$ is the thermal transmittance of

the frame (in $W/m^2K$), $U_t$ is the thermal transmittance of the transoms (in $W/m^2K$), $U_m$ is the thermal transmittance of the mullions (in $W/m^2K$), $U_{gb}$ is the thermal transmittance of the glazing bars (in $W/m^2K$), $\psi_{gf}$ is the linear thermal transmittance due to the combined thermal effects of the glazing, spacer and frame/sash ($W/mK$), $\psi_{gt}$ is the linear thermal transmittance due to the combined thermal effects of the glazing, spacer and transoms ($W/mK$),$\psi_{gm}$ is the linear thermal transmittance due to the combined thermal effects of the glazing, spacer and mullions ($W/mK$),$\psi_{ggb}$ is the linear thermal transmittance due to the combined thermal effects of the glazing, spacer and glazing bars ($W/mK$) and $g_g$ is the total solar energy transmittance. In *Fig. 1* the different components of a window are presented.

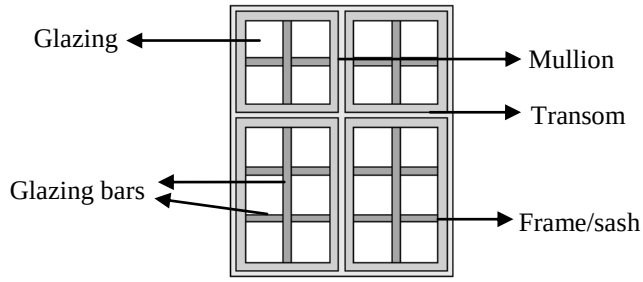


*FIG. 2 - Sketch in which the different possible components of a window are represented.*

### 2.2.2 The user interface of the program

In this first step, the user has the opportunity to set up different types of windows varying the configuration, size and components. For each type of window (which consists of a combination of configuration, size and components), the net energy gain for the reference house is calculated as described previously. The result is presented in a table, similar to the one shown in *FIG.2*, which makes it easier to compare the energy performance of different window types in an early design phase.

There are some default defined configurations that the user can pick in order to optimize the process of selecting windows. On the other hand, if the desired configuration is not available the user may create it by inserting its geometric characteristics. This option makes the procedure fast and flexible.

Regarding the windows components (glazing, frame/sash, transoms, mullions and glazing bars), there are pre-defined lists of possible solutions from which the user can create his window. For each type of component the possible solutions are organized in energy classes and a correlation is made between these classes and real products available in the market. Furthermore, the user can add new components to the existing lists by inserting their thermal properties.

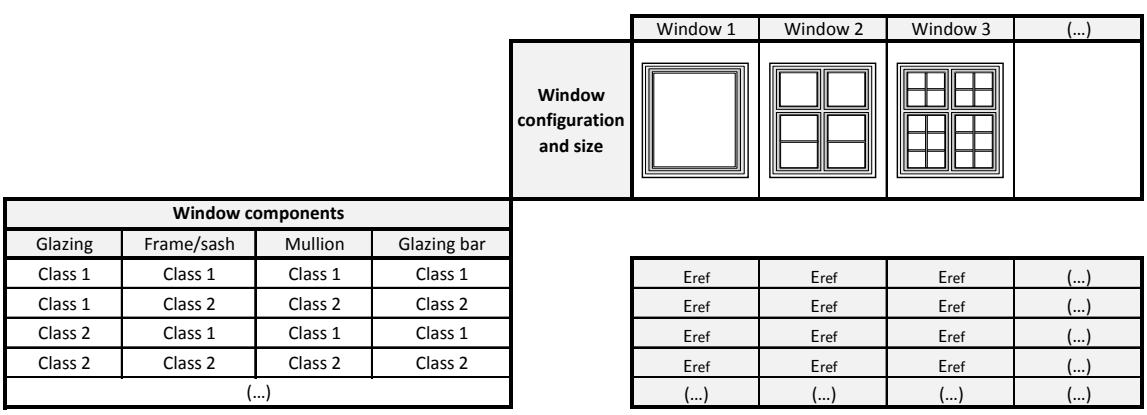


*FIG. 2 - Sketch of the user interface in Step 1.*

## 2.3 Step 2: Energy use due to windows - Seasonal Calculation

### 2.3.1 The method

Picking from the window types characterized during the previous step, in this stage the user is able to create different combinations of windows that can be integrated in the dwelling. For each combination the energy performance is calculated on a seasonal basis (heating and cooling seasons).

First, the energy use is calculated for each window, *k*, for the heating and cooling seasons. The difference from the previous step is that this energy use is calculated for the window being part of the actual house and not for a reference house. For the heating season, the energy use of each window *k*, is the difference between the heat losses and the solar gains that occur through the window during the heating season, taking into account the dimensionless utilization factor of the solar gains (equation *(4)*). In the same way, for the cooling season, for each window *k*, the energy use is the difference between the solar gains and the heat losses that occur through the window during the cooling season, taking into account the dimensionless utilization factor of the heat losses (equation *(5)*). The heat losses, solar gains and utilization factors are calculated according to CEN (2007, prEN ISO 13790).

$$E_{HS,k} = \underbrace{U_{w,k} \cdot A_{w,k} \cdot G_{HS}}_{\text{Heat losses}} - \eta_{HS} \cdot \underbrace{F_{sh,k} \cdot A_{sol,k} \cdot I_{sol,HS,k}}_{\text{Solar Gains}} \; [kWh] \qquad (4)$$

$$E_{CS,k} = \underbrace{F_{sh,k} \cdot A_{sol,k} \cdot I_{sol,CS,k}}_{\text{Solar Gains}} - \eta_{CS} \cdot \underbrace{U_{w,k} \cdot A_{w,k} \cdot G_{CS}}_{\text{Heat losses}} \; [kWh] \qquad (5)$$

where $U_{w,k}$ is the thermal transmittance of the window *k* (in $W/m^2K$), $A_{w,k}$ is the area of the window *k* (in $m^2$), $G_{HS}$ is the number of degree-hours during the heating season in Denmark (in $kKh$) - calculated for a reference indoor temperature of 20ºC using the Danish Reference Year (Jensen J.M. and Lund H., 1995), $G_{CS}$ is the number of degree-hours during the cooling season in Denmark (in $kK.h$) - calculated for a reference indoor temperature of 26ºC using the Danish Reference Year (Jensen J.M. and Lund H., 1995), $F_{sh,k}$is the shading reduction factor, for the window *k*, due to external obstacles - calculated according to (CEN, 2007, prEN ISO 13790), it takes into account the shadings from horizon, overhangs, fins and movable solar shading devices, $A_{sol,k}$ is the effective collecting area of the window *k* with a given orientation and tilt angle (in $m^2$) - calculated according to (CEN, 2007, prEN ISO 13790), $I_{sol,HS,k}$ is the mean energy of the solar irradiation over the heating period per square metre of the window *k*, with a given orientation and tilt angle (in $kWh/m^2$) - calculated using the Danish Reference Year (Jensen J.M. and Lund H., 1995), $I_{sol,CS,k}$ is the mean energy of the solar irradiation over the cooling period per square metre of the window *k*, with a given orientation and tilt angle (in $kWh/m^2$) - calculated using the Danish Reference Year (Jensen J.M. and Lund H., 1995), $\eta_{HS}$ is the dimensionless utilization factor for the solar gains during the heating season - determined according to (CEN, 2007, prEN ISO 13790) and $\eta_{CS}$ is the dimensionless utilization factor for the heat losses during the cooling season - determined according to (CEN, 2007, prEN ISO 13790).

In order to obtain the energy use of each window *k* integrated in the dwelling during the heating and cooling seasons (equations *(4)* and *(5)*), some new information must be provided by the user in this step. In order to calculate the solar gains, information is required regarding shadings from horizon, overhangs, fins and movable solar shading devices, as well as the orientation and tilt angle of the windows. For the calculation of the utilization factors for the solar gains and heat losses, information is required regarding the thermal performance and thermal capacity of the construction, as well as the type of ventilation system.

The overall energy use of the windows of the dwelling, during the heating season, is given by equation *(6)*. A similar calculation is performed for the cooling season in equation *(7)*.

$$E_{HS} = \sum_{k, if\, E_{HS,k}>0} \frac{E_{HS,k}}{A_f} [kWh/m^2] \qquad (6)$$

$$E_{CS} = \sum_{k, if\, E_{CS,k}>0} \frac{E_{CS,k}}{A_f} [kWh/m^2] \qquad (7)$$

where $E_{HS}$ is the overall energy use of the windows of the dwelling during the heating season (in $kWh/m^2$), $E_{CS}$ is the overall energy use of the windows of the dwelling during the cooling season (in $kWh/m^2$), $E_{HS,k}$ is the energy use of each window *k* during the heating season (in $kWh$), $E_{CS,k}$ is the energy use of each window *k* during the cooling season (in $kWh$) and $A_f$ is the heated floor area of the dwelling (in $m^2$).

Summing $E_{HS}$ and $E_{CS}$, the overall energy use of the windows of the dwelling is obtained for a whole year.

### 2.3.2 The user interface of the program

In this step, the user can create different combinations of windows for the dwelling and compare their energy performance on a seasonal basis (heating and cooling seasons). For each combination, the user must specify the windows according to the room in which they are placed, their orientation, type, tilt angle and shadings (from horizon, overhangs, fins or movable solar shading devices). The windows types can be selected from the ones previously characterized in *Step 1*, or they can be inserted in terms of thermal transmittance, total solar energy transmittance and area of the window.

The user must also provide some general information about the dwelling, such as floor area, thermal capacity and thermal transmittance of the construction, as well as type of ventilation system. As an alternative some default values are available for typical buildings.

The definition of the rooms would not be required for the calculation procedure in this step. However, this information is asked in order to facilitate the use of *Step 3*, in which the calculation is performed for each room. If *Step 3* is not desired, in *Step 2*, the windows may all be defined in one single room.

The result is the energy use of each combination of windows applied to the dwelling for the heating and cooling seasons. The result for the whole year is also presented. In this way, the user can select from different combinations of windows the ones with optimal energy performance.

A scheme of the user interface for this step is presented in *FIG. 3*.

| | | Combination 1 | Combination 2 | Combination 3 | (...) |
|---|---|---|---|---|---|
| | | **Room 1** | **Room 1** | **Room 1** | (...) |
| | | (orientations,windows types, number of windows, tilt angles, shadings from horizon, overhangs, fins and movable solar shading devices) | (orientations,windows types, number of windows, tilt angles, shadings from horizon, overhangs, fins and movable solar shading devices) | (orientations,windows types, number of windows, tilt angles, shadings from horizon, overhangs, fins and movable solar shading devices) | (...) |
| | | **Room 2** | **Room 2** | **Room 2** | (...) |
| | | (...) | (...) | (...) | (...) |
| | | **Room 3** | **Room 3** | **Room 3** | (...) |
| | | (...) | (...) | (...) | (...) |
| | | (...) | (...) | (...) | (...) |
| **windows energy consumption** | **heating season** | $E_{HS,1}$ | $E_{HS,2}$ | $E_{HS,3}$ | (...) |
| | **cooling season** | $E_{CS,1}$ | $E_{CS,2}$ | $E_{CS,3}$ | (...) |
| | **total** | $\mathbf{E_{Tot,1}}$ | $\mathbf{E_{Tot,2}}$ | $\mathbf{E_{Tot,3}}$ | **(...)** |

*FIG. 3 - Sketch of the user interface in Step 2.*

## 2.4 Step 3: Indoor environment and energy use due to windows - Hourly calculation

### 2.4.1 The method

From the previous step, the user obtains the energy use of different combinations of windows applied to the dwelling on a seasonal calculation basis. However, a low energy use obtained with a seasonal calculation does not mean that the indoor climate level required by (CEN, 2007, EN 15251) is fulfilled for every hour of the year. In this way, it is important to perform an hourly calculation to check if the combination of windows previously selected, as having a low seasonal energy use, also guarantee a good level of indoor climate. To perform the hourly calculation, the method used is the *simple hourly method* described in (CEN, 2007, prEN ISO 13790).

Using this method, an hourly calculation may be performed for critical rooms of the dwelling in order to evaluate the indoor climate. For each of the critical rooms, the air temperature, $\theta_{air}$, is calculated for every hour and, if the temperature obtained is not inside the range defined by the heating and cooling setpoints, the energy needed for heating or cooling in order to set back the temperature inside the comfort range is calculated. The room annual energy needs for heating and cooling are obtained by summing the energy needs for heating and cooling, respectively, for every hour.

### 2.4.2 The user interface of the program

In this step, the user may select, from *Step 2*, the critical rooms for which he wants the hourly calculation to be performed. For every hour, the air temperature, $\theta_{air}$, and the energy needs for heating and cooling are calculated. In this way, it is possible to ensure that the windows solutions previously selected, as having a good energy performance, also provide a good level of indoor comfort.

This step can be performed for different rooms and the different combinations of windows previously defined may be compared. If the indoor comfort is not accomplished, the windows solutions may be improved including the definition of better use of the solar shading devices.

If *Step 3* is applied to all the rooms of the dwelling, the annual heating and cooling demands of the whole dwelling may be determined, on an hourly basis, by summing the annual energy demand of each room.

## 2.5 Step 4: Cost of conserved energy due to windows

### 2.5.1 The method

After evaluating the energy performance of different combinations of windows and their influence on the indoor environment, in this step, it is possible to perform a simple economic evaluation for the lifetime of windows.

For each combination of windows defined in *Step 2*, the cost of conserved energy, $CCE$, for the lifetime of the windows, can be calculated according to equation *(8)*:

$$CCE = \frac{I - I_{ref}}{E_{ref} - E} \cdot \frac{d}{1-(1+d)^{-n}} \; [DKK/kWh] \qquad (8)$$

where $(I - I_{ref})$ represents the investment cost, defined as the difference between the cost of the combination of windows and the cost of a reference combination (in Danish kroner), $(E_{ref} - E)$ represents the annual savings, expressed as the difference between the energy use of the reference combination of windows and the energy use of the actual combination, calculated on a seasonal basis (in $kWh$), $n$ is the economic evaluation period taking into account the lifetime of the windows (usually 30 years) and $d$ is the net discount rate.

The investment cost only includes the initial cost of the windows. No costs for maintenance are included since significant variations may occur depending on each particular situation. The costs are defined for the entire windows.

The reference combination of windows may vary according to the purpose. If the purpose is to replace the windows solution of the house, the reference should be the existing windows solution. If the purpose is the design of a new

house, then the reference solution may be the poorer solution available in the market that still fulfils the building code requirements.

The lifetime of the windows is simply assumed to be 30 years, based on the individual lifetime of the glazing units and frames, which are around 20 and 40 years, respectively.

Finally, the cost of conserved energy, in DKK/kWh, may be compared between different possible combinations of windows and with the cost of the energy type used to provide heating and cooling. This should be the procedure to ensure that the investment is profitable.

### 2.5.2 The user interface of the program

As stated before, in this step, the user is able to evaluate the economic performance of different combinations of windows, previously defined in *Step 2*, in comparison to a reference combination. The economic evaluation is made in terms of cost of conserved energy for the life time of the windows.

The user must specify the reference combination of windows that will be used, costs, lifetime and net discount rate. However some values are suggested as default.

# 3. Conclusion

Based on the results of all the steps, an overall performance of different combinations of windows regarding energy, indoor climate and economics is provided, for the user to select the optimal solution of windows for the dwelling.

In this way, it is our hope that once the tool is completed, tested and validated, the full potential of optimizing the energy performance of dwellings by optimizing the selection of windows can be used in an easy way.

# 4. Acknowledgments

This project was financed by Boligfonden Kuben.

# 5. References

CEN (2007, EN 15251). EN 15251, Indoor environment input for design and assessment of energy performance of buildings addressing indoor air quality, thermal environment, lightning and acoustics.

CEN (2007, prEN ISO 13790). prEN ISO 13790, Energy performance of buildings - Calculation of energy use for space heating and cooling.

Jensen J.M. and Lund H. (1995). Design Reference Year, DRY - a new Danish Reference Year (in Danish: et nyt dansk reference år), Department of Buildings and Energy, Technical University of Denmark, in Danish.

Mitchell R., Huang J., Arasteh D., Huizenga C. and Glendenning S. (2005). RESFEN 5: A PC program for calculating the heating and cooling energy use of windows in residential buildings - Program Description, Lawrence Berkeley National Laboratory, Berkeley, USA.

Nielsen T. R., Duer K. and Svendsen S. (2001). Energy performance of glazings and windows, Solar Energy, Vol. 69 (Suppl.) Nos. 1-6, 137-143.

Svendsen S., Kragh J. and Laustsen J. B. (2005). Energy performance of windows based on net energy gain, 7th Symposium on building physics in the Nordic countries, Reykjavik.

**BILAG 2**

**8TH Nordic Symposium Building Physics**

**Præsentation**
**Tool for selection of windows in dwellings**

# Tool for selection of windows in dwellings

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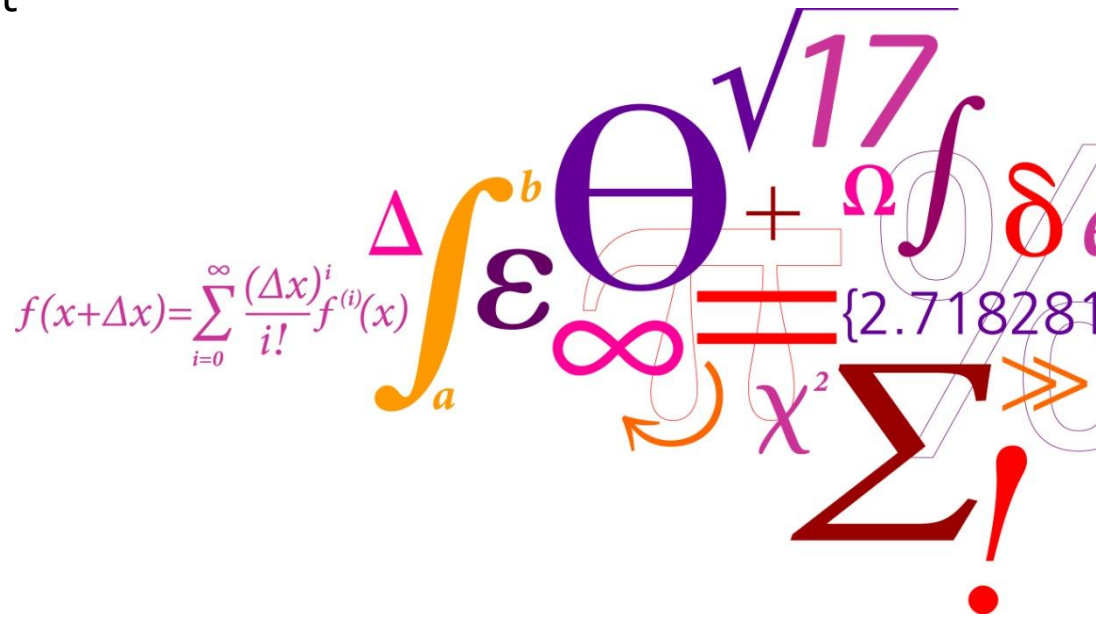
June 16th 2008




DTU Civil Engineering
Department of Civil Engineering

# Project goal

Tool to optimize the selection
of windows in dwellings

Microsoft Excel and
VBA

Energy performance
Indoor thermal climate
Economic evaluation

User-friendly
Flexible

To be used by
architects and engineers

Design of new dwellings
Renovation of old dwellings

# The method

The selection of windows is organized in 4 different stages:

**STEP 1**

Window net energy gain

**STEP 2**

Seasonal energy performance of windows in dwelling

**STEP 3**

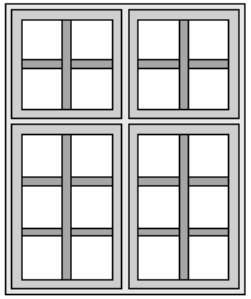
Hourly energy performance and thermal comfort of windows in room

**STEP 4**

Economical performance of windows

# STEP 1

Net energy gain of individual windows



## INPUT

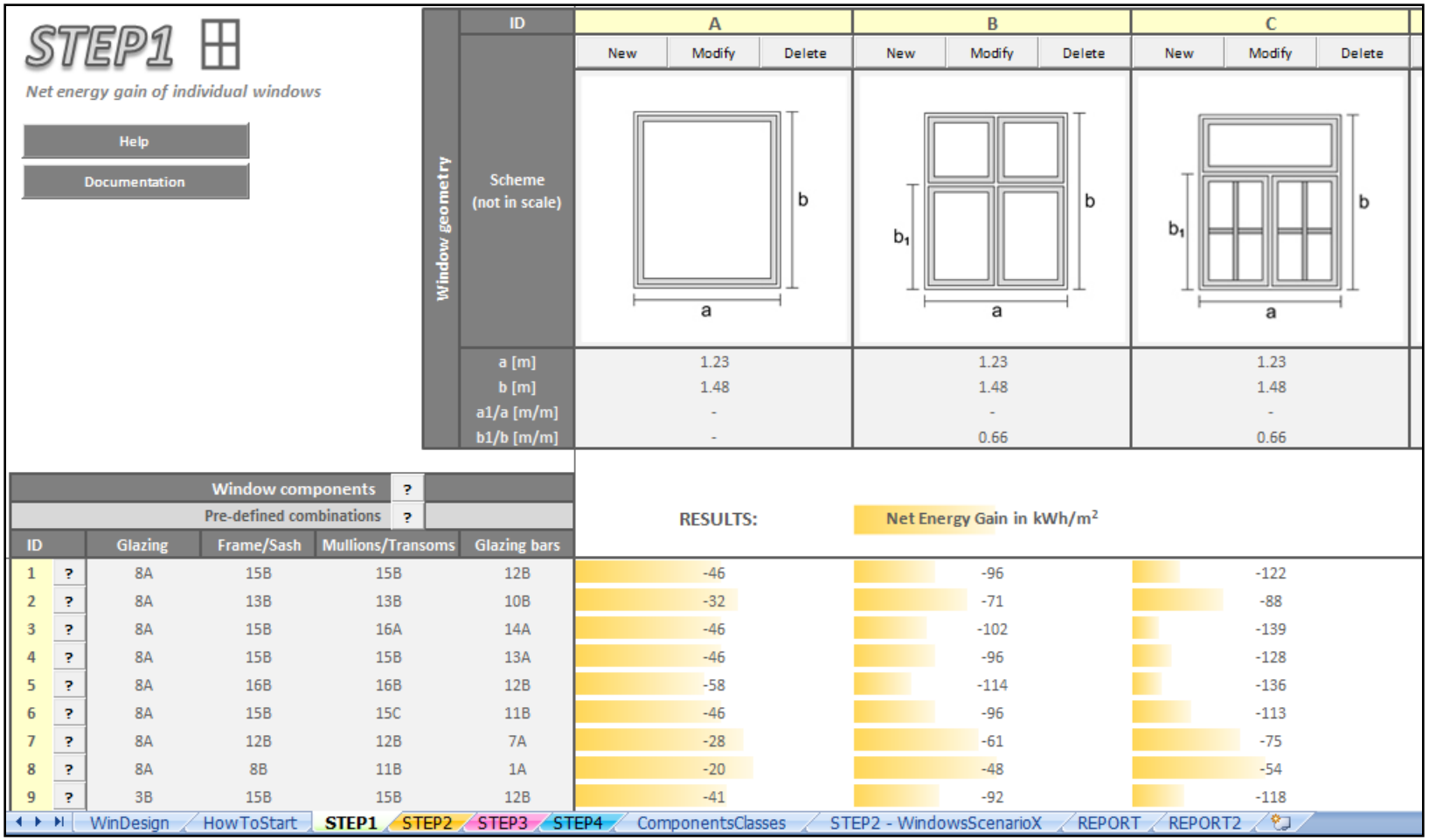
- Window geometry
- Thermal performance of the window components

## OUTPUT

- **Net energy gain** (heating season - reference house in Denmark)

$$E_{ref} = 196.42g_w - 90.36U_w \quad [kWh/m^2]$$

# STEP 1 - User Interface

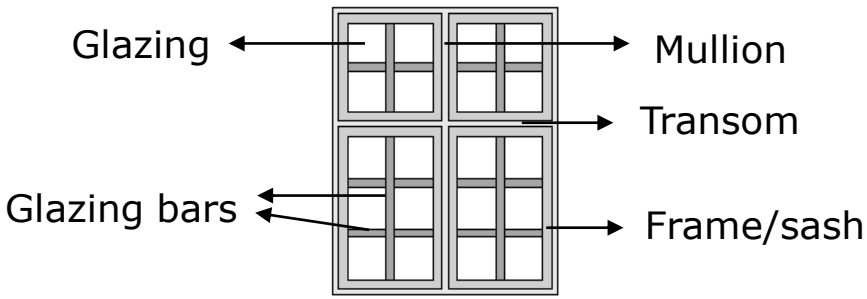


# STEP 1 - ENERGY CLASSES OF WINDOW COMPONENTS

**GLAZING**

Classes sorted according to:

- U-value [W/m$^2$K]
- g-value [-]




**FRAME/SASH**

Classes sorted according to:

- $L_{joint}$ [W/mK]
- width [m]

$$L_{joint} = U \times w + \Psi$$

**MULLIONS/TRANSOMS and GLAZING BARS**

Classes sorted according to:

- $L_{joint}$ [W/mK]
- width [m]

$$L_{joint} = U \times w + 2 \times \Psi$$

# STEP 2

Energy consumption of the windows used in the dwelling

Seasonal calculation - ISO 13790

**INPUT**

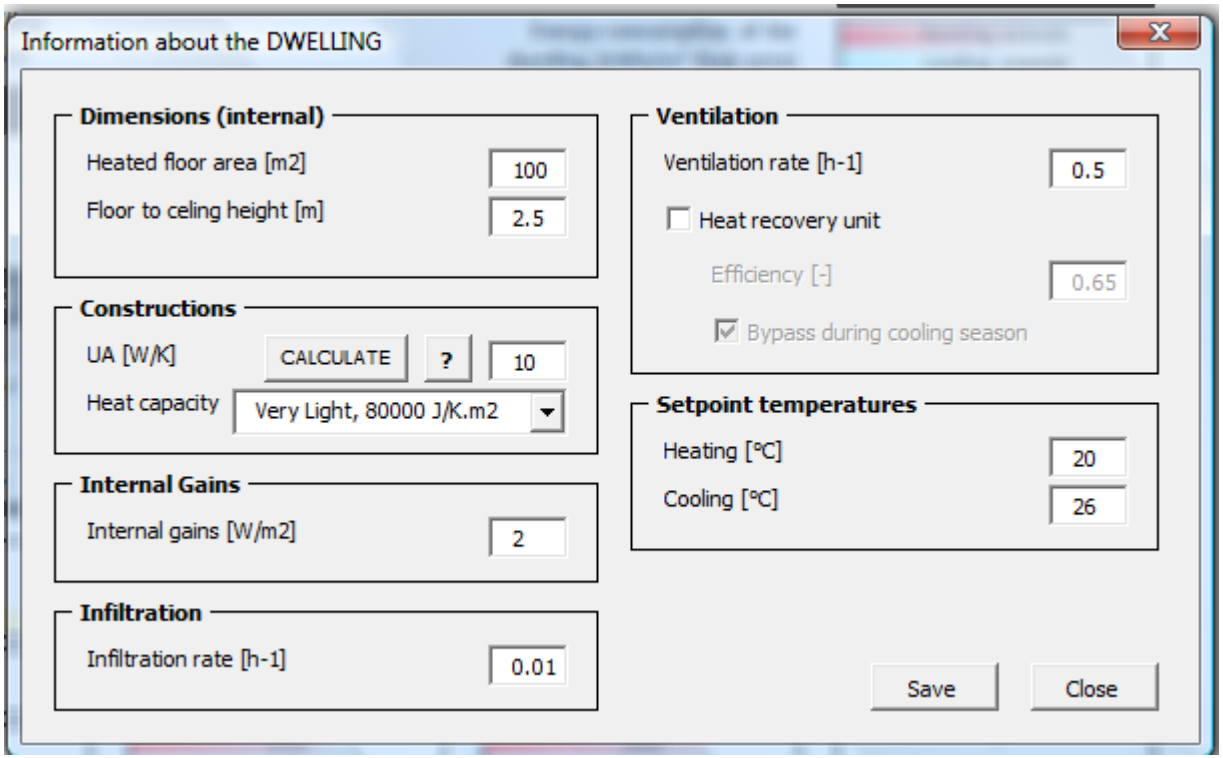
- Information about the dwelling
- Information about the windows used in the dwelling
  (geometry, components, orientation, shadings from horizon, overhang and fins, shading device)
- Different scenarios of windows

**OUTPUT**

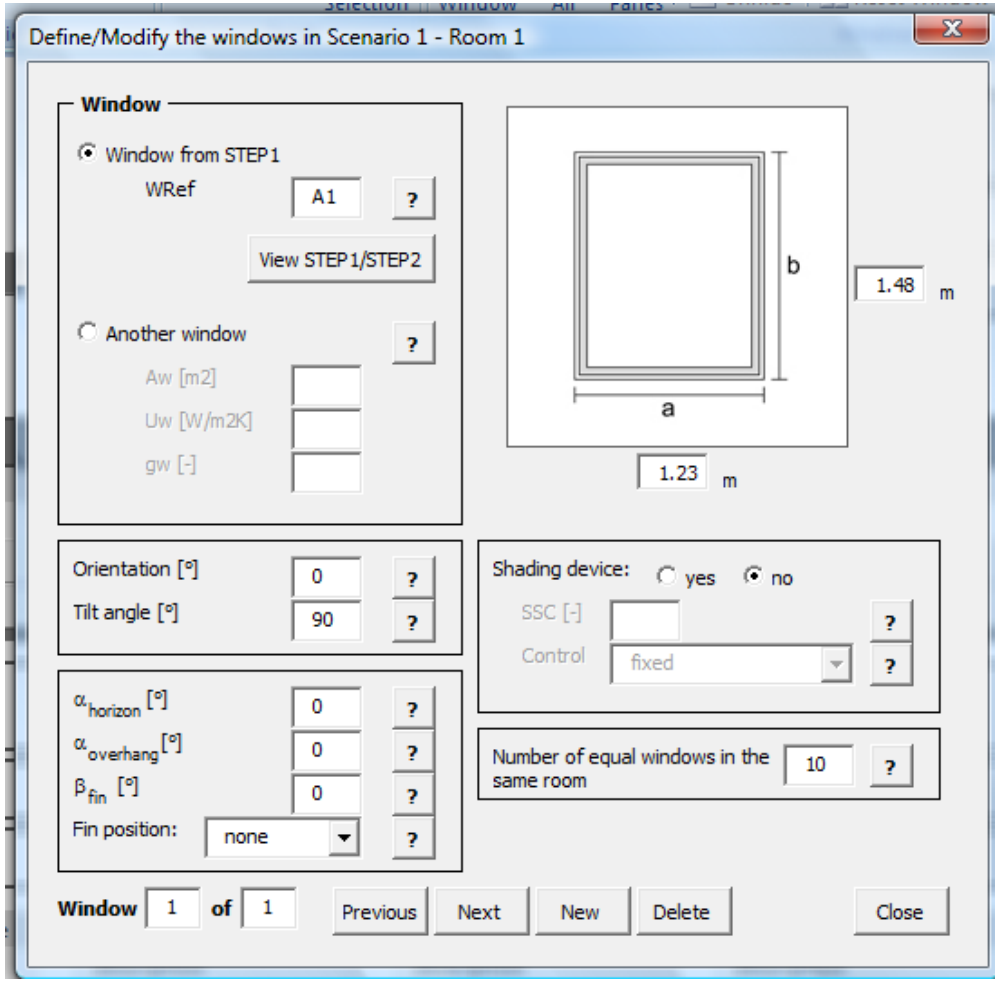
For each scenario:

- Energy consumption of the windows used in the dwelling
- Energy consumption of the dwelling
- Length of heating and cooling seasons

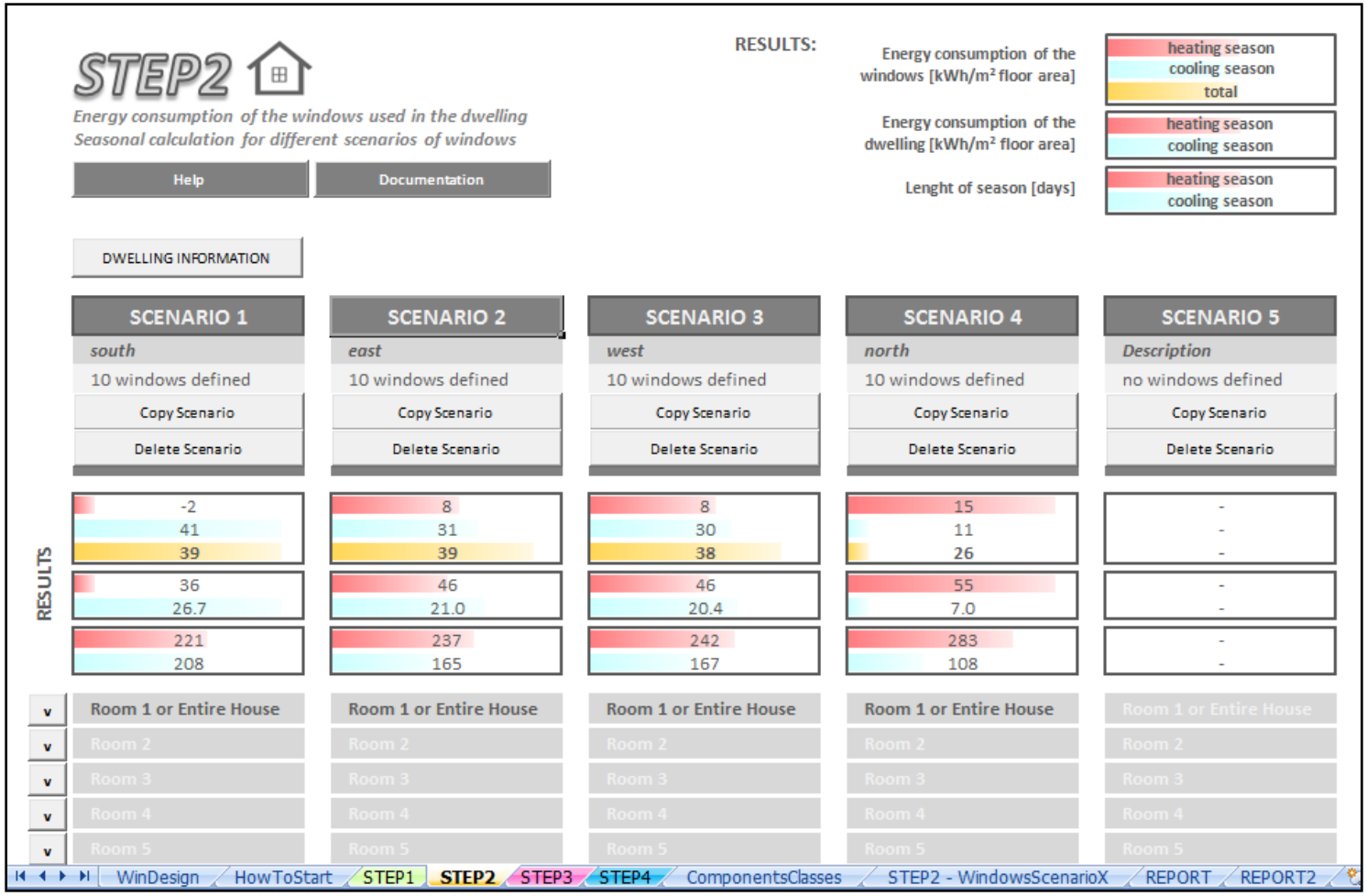
# STEP 2 - User Interface



# STEP 2 - User Interface



# STEP 2 - User Interface



# STEP 3

Energy consumption and indoor temperature of a room of the dwelling
Hourly calculation – *Simple Hourly Method* in ISO 13790

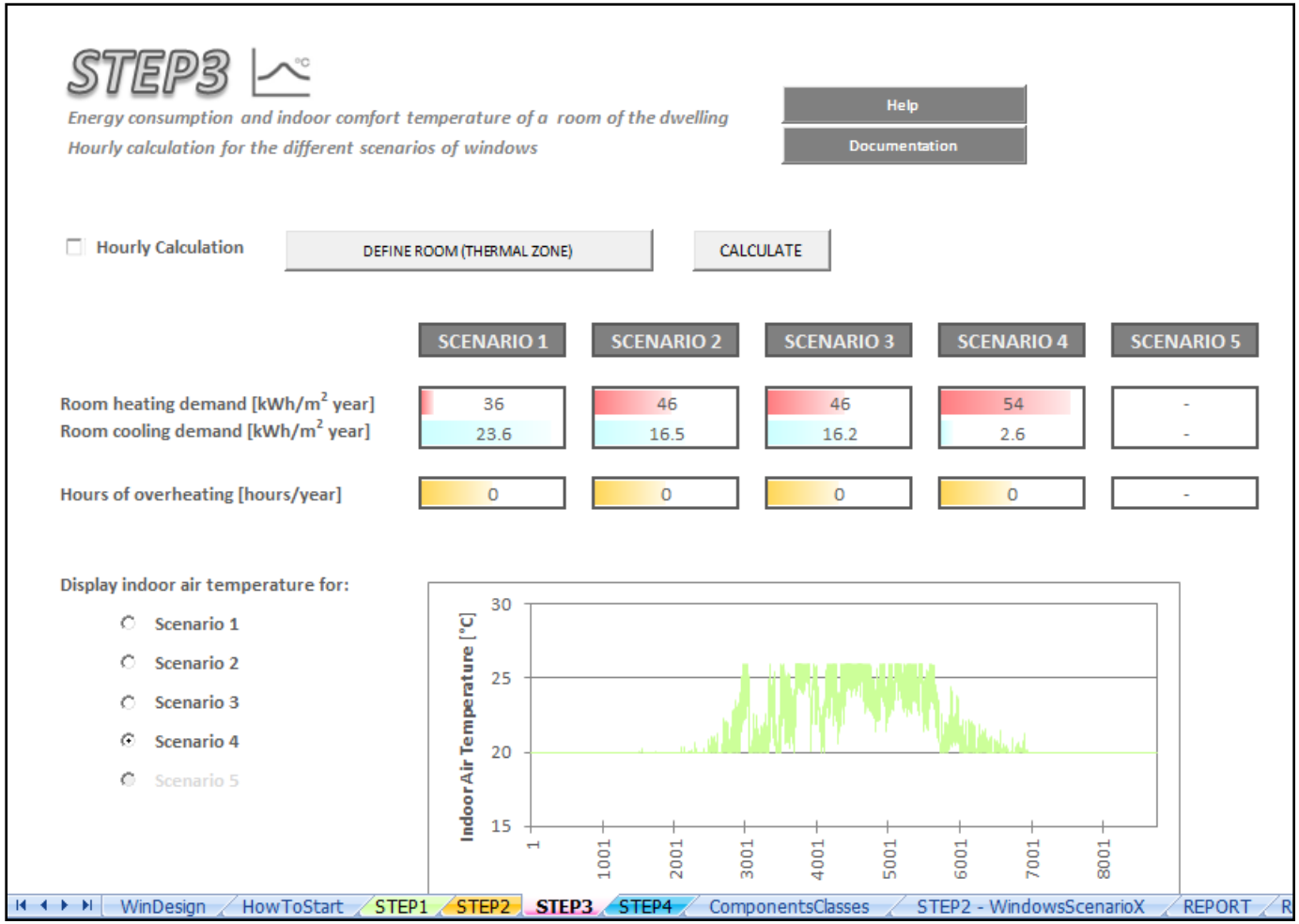
## INPUT

- Information about the room

## OUTPUT

For each scenario:
- Room heating/cooling demand
- Number of hours with overheating

# STEP 3 - User Interface



# STEP 4

Cost of conserved energy

## INPUT

- Identify the reference scenario
- Economic evaluation period
- Net discount rate
- Total windows cost for each scenario

## OUTPUT

For each scenario:

- Cost of conserved energy compared to the reference scenario in DKK/kWh

# STEP 4 - User Interface

STEP4

*Cost of conserved energy for the different scenarios of windows*

Help

Documentation

| REFERENCE | |
|---|---|
| Scenario number | SCENARIO 4 |
| Windows energy consumption [kWh] | 1491 |
| Total windows cost [DKK] | 1000 |

| | | |
|---|---|---|
| n [years] | 30 | ? |
| d [-] | 0.07 | ? |
| mechanical cooling | no | ? |

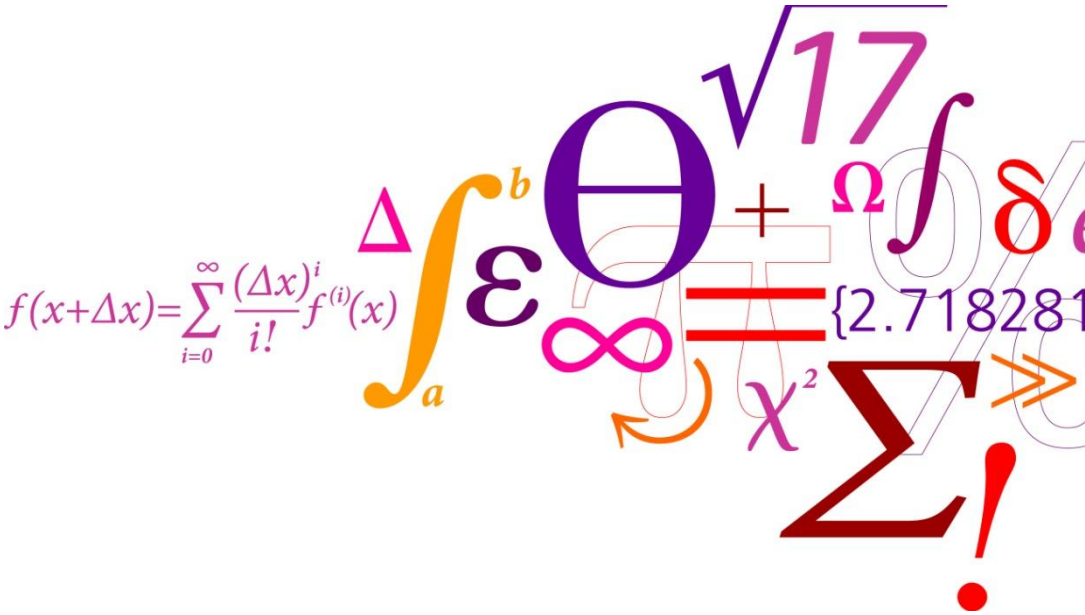
| | SCENARIO 1 | SCENARIO 2 | SCENARIO 3 | SCENARIO 4 | SCENARIO 5 |
|---|---|---|---|---|---|
| Cost of conserved energy [DKK/kWh] | 0.10 | 0.11 | 0.11 | reference | - |
| Windows energy consumption [kWh] | -187 | 766 | 751 | 1491 | - |
| Total windows cost [DKK] | 3000 | 2000 | 2000 | 1000 | 0 |
| Annual savings [kWh] | 1678 | 724 | 740 | - | - |
| Investment cost [DKK] | 2000 | 1000 | 1000 | - | - |

WinDesign | HowToStart | STEP1 | STEP2 | STEP3 | STEP4 | ComponentsClasses | STEP2 - WindowsScenarioX | REPORT | R

# Conclusion

Results from all STEPs

↓

Selection of the optimal solution of windows for the dwelling

# Thank you