Tool for Selection of Windows in Dwellings

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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.

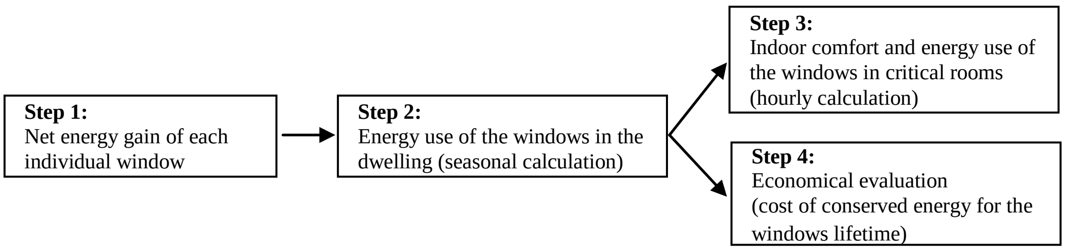


FIG. 2 - Sketch with the overview of the method and calculation program.

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), ψ_{gf} is the linear thermal transmittance due to the combined thermal effects of the glazing, spacer and frame/sash (W/mK), ψ_{gt} is the linear thermal transmittance due to the combined thermal effects of the glazing, spacer and transoms (W/mK),ψ_{gm} is the linear thermal transmittance due to the combined thermal effects of the glazing, spacer and mullions (W/mK),ψ_{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.

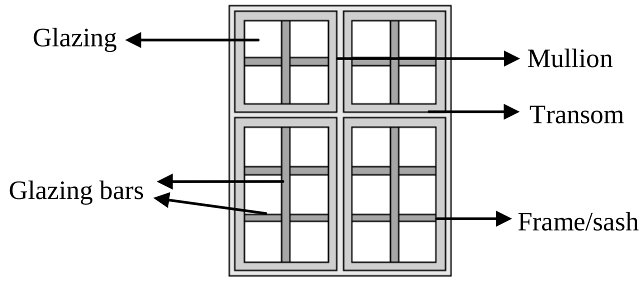


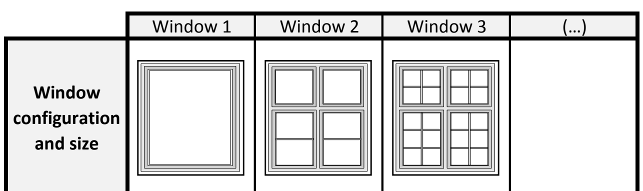
FIG. 2 - Sketch in which the different possible components of a window are represented.

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.



Window components			
Glazing	Frame/sash	Mullion	Glazing bar
Class 1	Class 1	Class 1	Class 1
Class 1	Class 2	Class 2	Class 2
Class 2	Class 1	Class 1	Class 1
Class 2	Class 2	Class 2	Class 2
(...)			

Window 1	Window 2	Window 3	(...)
Eref	Eref	Eref	(...)
Eref	Eref	Eref	(...)
Eref	Eref	Eref	(...)
Eref	Eref	Eref	(...)
(...)	(...)	(...)	(...)

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), η_{HS} is the dimensionless utilization factor for the solar gains during the heating season - determined according to (CEN, 2007, prEN ISO 13790) and η_{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, θ_{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, θ_{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

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