Technical University of Denmark

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Christensen, Jørgen Erik

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Simulation of thermal indoor climate in buildings by using human Projected Area Factors

J. E. Christensen
Danish Technical University, Department of Civil Engineering, Kgs. Lyngby, Denmark

ABSTRACT: Nowadays many new and old buildings in Denmark have large glass surfaces. This is a consequence of the technical development of windows with low U-values that has made it possible to build houses with windows from floor to ceiling in northern climates. On the other hand if one is sitting close to these large windows on a cold winter day it is recognized that this can cause thermal discomfort. The calculation of this discomfort needs to be taken properly into account in the simulation of the thermal indoor climate and energy consumption of the rooms. The operative temperature can be used as a simple measure for thermal environment. The operative temperature is a function of the air temperature, the mean radiant temperature and the relative air velocity. However, in many programs for calculation of energy consumption and thermal indoor climate the model for calculating the mean radiant temperature has traditionally been based on the calculation of an area weighted mean value independently of the location in the room. In practice the location of the person in the room has a significant influence and inhomogeneous radiation plays an important role for the usability and functionality of the room. In order to calculate the mean radiant temperature as function of the person´s location in the room one needs to calculate the angular factor between the person and the surfaces. This paper describes a method for detailed calculation of the operative temperature and how it can be implemented in programs for dynamic building thermal analysis. The method is demonstrated in a newer apartment with windows from floor to ceiling and shows how impotent it is to include the radiant effect from the glass surfaces and how it influences the indoor thermal climate significantly.

1 INTRODUCTION

Simulation of energy consumption in buildings on hourly basis is closely connected to the thermal indoor climate. However in many programs the model for calculating the indoor climate has traditionally been based on a relatively simple model for the operative temperature independently of the location of the person in the room. In practice the location of the person has a significant influence in buildings with greater glass surfaces.

The outside air temperature and the solar radiation are closely related to the temperatures on the surface of the walls and the windows. Since the insulation of walls in Scandinavia is 4 to 15 times better than the insulation of the glass, the inside surface temperature is much more affected on the inside of the glass than on the inside of the wall. Designing rooms with big glass areas therefore has a great effect on the thermal comfort in the rooms. When calculating the consequences for the indoor thermal climate, the surface temperature is an important factor. To find a simple measure for the heat loss from a person, the operative temperature can be used. The operative temperature is a function of the air temperature, the mean radiant temperature and the relative air velocity. The mean radiant temperature plays an important part in calculating the operative temperature.

The surface temperature can easily be measured or calculated. However, the angular factor between a sedentary/standing person and a rectangle on the wall, floor or ceiling is far more complicated to calculate seeing that the Human Projected Area Factor is involved in this calculation. Since it is complicated to measure the Human Projected Area Factor, results from resent research are used as a background to set up a simpler model to be used in simulation programs on hourly basis for energy consumption and indoor climate. The model can be used for simulation of the operative temperature dependently of the location of the person in the room. The model described in this paper can easily be implemented in simulation programs for energy consumption and indoor climate thus making a picture of different locations in the room throughout the year. The program can be used with different Human Projected Area Factors according to the actual case, or for comparing different models.

2 THE MEAN RADIANT TEMPERATURE AND THE OPERATIVE TEMPERATURE

The idea behind the operative temperature is to simplify complicated thermal conditions, where the air temperature, the radiant temperature and the air movement are involved. The operative temperature is the uniform temperature of the air and the surfaces, which gives the same heat loss, from a human person, as the real actual conditions. In traditional buildings where the difference between the air temperature and the mean radiant temperature is less than 4 K and the relative air velocity is less than 1 m/s the operative temperature can be calculated from the following formula, (ISO 7730, 1994):

$$t_o = A \cdot t_a + (1 - A) \cdot t_r \tag{1}$$

where t_o = the operative temperature [ºC], t_a = the air temperature [ºC], t_r = the mean radiant temperature [ºC], A = a factor accordance to the relative air velocity (A=0.5 for v_{ar}< 0.2 m/s, A=0.6 for v_{ar}= 0.2-0.6 m/s, A=0.7 for v_{ar}= 0.6-1.0 m/s).

The air temperature is the temperature in the occupied zone (Hansen et al, 2006), outside the persons boundary zone where the body heat from the person heats the air. The average air temperature has an influence on the person's convective heat loss and for a sedentary person it is recommended to measure in 0.6 m high over the floor equivalent to the person's centroid.

The mean radiant temperature $\bar{t}_{r,P}$ is defined as the uniform temperature of the surrounding surfaces, which will result in the same heat loss by radiation from a person as the actual conditions of the surroundings (Hansen et al, 2006). The mean radiant temperature between a person and the surrounding surfaces can be calculated from (Hansen et al, 2006):

$$\bar{t}_{r,P} = F_{P-1} \cdot t_1 + F_{P-2} \cdot t_2 + \ldots\ldots.. + F_{P-n} \cdot t_n \tag{2}$$

where $t_{r,P}$ = the mean radiant temperature for a person [ºC], t_i = the temperature of surface i [ºC], F_{P-i} = the angular factor between a person and surface i [–].

In simulation programs on hourly basis for energy consumption and indoor climate in buildings, the surface temperatures will usually easily be calculated. However, the angular factor between a sedentary/standing person and a rectangle on the wall, floor or ceiling is far more complicated to calculate. In most cases the angular factor is read from a figure since there is no exact formula for calculation of the angular factor between a person and a surface. As a result of this most programs use an area average waited value in the calculation of the mean radiant temperature. The consequences of this are that the location of the person in the room has no influence on the result.

3 PLANS FOR IMPLEMENTATION OF THE MODEL IN THE PROGRAM BSIM

It is planned to implement the developed model in the computer program software package (BSim, 2005). The author of this paper has been a co-developer of the program in a former version *tsbi3* released in 1990 (Johnsen & Grau & Christensen, 1993) (Johnsen & Grau, 1994). Later, the program has been incorporated as *tsbi5* into the computer program software package (BSim, 2005).

BSim is being used for research and commercial calculations by consulting engineers in the field of heating and air-conditioning. The program provides means for detailed, combined hygrothermal simulations of buildings and constructions. BSim can be used for analyzing indoor climate, energy consumption, passive solar energy, automatic control functions, etc. in connection with the planning and design of buildings, energy-conservation measures, renovation of buildings, and heating and air-conditioning systems. The program is the most used program in this field in Denmark.

This paper deals with a suggestion on how to improve the model in *tsbi5* for the operative temperature for a specific location in the room, since *tsbi5* only calculates the mean radiant temperature as an area weighted mean value.

4 ANGLE FACTOR BASED ON THE PROJECTED AREA FACTOR

When one wants to find the angular factor between two surfaces, one can find a specific equation for the angular factor to be used in the calculations. However, the real problem is to calculate the mean value of the angular factor between a sedentary/standing person and a vertical/horizontal rectangle since there are no direct formula for calculation of the angular factor between the surface and a person. The problem is solved by introducing the *projected area factors* f_p (Fanger, 1972):

$$f_p = \frac{A_p}{A_{eff}} \quad \wedge \quad F_{P-A2} = function(f_p) \tag{3}$$

where A_{eff} = the effective radiation area of the subject, A_p = projected area of a person on a plane perpendicular to the direction to d_{A2}, F_{P-A2} = the angle factor between the person and the sphere *(A_2)*.

At the time when this theory (Fanger, 1972) was developed it was only possible to find a person´s projected area A_p from experiments. Later in this paper, newer methods will be described in which the human body has been modelled by using a detailed 3D geometry and radiation model.

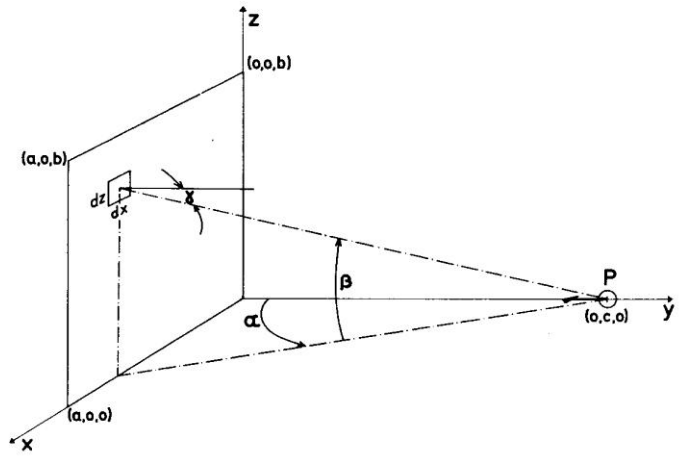

Figure 1. The geometric principle for development of the evaluation of the angle factor between a person and a rectangle (Fanger, 1972).

f_p as a function of the angles (α,β), figure 1, for a person located at $(0,c,0)$ in the orthogonal coordinates system (x,y,z) facing towards the system´s zero point, can according to Fanger (1972) be derivate for each differential area elements ($dA=dx,\ dy$) by inserting the correlation between the orthogonal coordinates and the angles:

$$\alpha = \arctan\left(\frac{x}{y}\right) \tag{4}$$

$$\beta = \arctan\left[\frac{\frac{z}{y}}{\sqrt{\left[\frac{x}{y}\right]^2+1}}\right] \tag{5}$$

where α and β are the angles on figure 1 and $x,\ y,\ z$ coordinates in figure 1. The reciprocity theorem (Cengel, 1997):

$$dA \cdot dF_{dA-P} = A_{eff} \cdot dF_{P-dA} \tag{6}$$

where $dF_{dA\text{-}P}$ = the angle factor between dA and the person and $dF_{P\text{-}dA}$ = the differential angle factor between the person (P) and dA. In the next step the angle factor $F_{P\text{-}A}$ between the person?? can be made for the whole rectangle A ($a \cdot b$) by making integration over all differential elements linked to the actual projected area factors f_p for (α,β):

$$F_{P-A} = \frac{1}{\pi} \cdot \int_{x=0}^{x=a} \int_{z=0}^{z=b} \frac{f_p \cdot y}{\left(x^2+y^2+z^2\right)^{\frac{3}{2}}}\, dx\, dz \tag{7}$$

From equation (7) the angle factor $F_{P\text{-}A}$ can be calculated as a function of the dimensionless relationship a/c and b/c, figure 1 / figure 3. In this way a simple diagram can be used manually to find the angle factor for a rectangle of any size, placed as shown in figure 1 with the normal at the corner point passing through the centre of the person.

To find an angle factor in a room in which a person is facing one of the walls, there will, according to (Fanger, 1972), be 6 cases, which means that 6 diagrams have to be drawn using equation (7): 4 vertical surfaces and 2 horizontal surfaces. In most cases the location of the person in the room will be known, however the person's orientation will change from time to time. This means that it will be natural to find the mean value of the angle factor for a person rotating around himself $\bar{F}_{P-A}$ ($0< \alpha < 2\pi$), meaning that for a vertical rectangle the angle factor can be found by using formulary (8) (Fanger, 1972):

$$\bar{F}_{P-A} = \frac{1}{2\cdot\pi^2} \int_{x/y=0}^{x/y=a/c} \int_{z/y=0}^{z/y=b/c} \int_{\alpha=0}^{\alpha=2\pi} \frac{f_p}{\left[1+\left(\frac{x}{y}\right)^2+\left(\frac{z}{y}\right)^2\right]^{\frac{3}{2}}}\, d\left(\frac{x}{y}\right) d\left(\frac{z}{y}\right) d\alpha \tag{8}$$

Since we now calculate the mean value of the angle factor between the person and the rectangle, where the person now is rotating around his own axis, we need to mark the angle factor as an average: $\bar{F}_{P-A}$. This simplification reduces the number of diagrams which need to be drawn from 6 to 2 – one for horizontal rectangles and one for vertical rectangles. In many literature references only the two diagrams for the person rotating around his own axis are shown, which can withdraw the users attention to the actual cases, where a person is often sitting with a 90 degree angle to the window. This leads to a result, where the angle factor in a 90 degree angle is underestimated with approximately 10% in relation to the rotating case, which leads to results to the unsafe side for example with a cold window surface.

5 PROJECTED AREA FACTOR FROM EXPERIMENTS

Several researchers have used different kinds of photographic methods to find the projected area factors f_p. Fanger (Fanger, 1972) is the researcher who did the most extensive experiments to determine f_p. Fanger performed his experiments for measuring A_p using a photographic technique of the persons from many different directions. From a given viewing angle each photo provided the projected area of the body. By taking photos it was possible to find the projected area of the body for all these angles – and then the projected area factors f_p can be calculated. In the study ten males and ten females participated in standing and sedentary positions for azimuth (α) and altitude (β) angels between 0º to 180º and 0º to 90º, respectively. The persons were a fair sample of the adult population.

In the experiment Fanger wanted for solar radiation to determine the projected area factor f_p, which is why the radiation rays should be as close as possible to be parallel, meaning that the distance between the person and the camera has to be infinite. In Fanger´s case he positioned the camera in a distance of about seven metres and was then able to make his experiment with quite a good approximation to the simulation of parallel rays from the subject to the radiant source. Fanger presented his results as a form of graphs.

Fanger showed that the projected area factor f_p can be used in practice independently of the clothing, size and sex of the person, however one has to distinguish between a standing and a sedentary human body. The consequence of this is that all the mean values of the f_p-values can be plotted into one diagram, e.g. for a sedentary human body, see figure 2.

The illustration in figure 2 for the projected area factor shows the factor as a function of the azimuth α and the altitude β to an infinitely small surface. Since equation (7) and (8) use the *projected area factor* – f_p, it is impossible to solve the equation exactly since f_p is a function of the azimuth α and the altitude β in an irregular way because it is based on experimental measurements from the human body. However it is possible from the actual measured data to make integration using equations (7) and (8) over all the angles for the azimuth α and the altitude β and draw a diagram for the angle factors between a human body and vertical or horizontal rectangles based on the mean values of f_p shown for a sedentary person in figure 2. If we look at the case with a fixed position for a person in a room but the facing of the person is unknown, the mean value of the angle factor can be found when the person rotates around a vertical axis. An example of the mean value of the angle factor between a sedentary human body and a

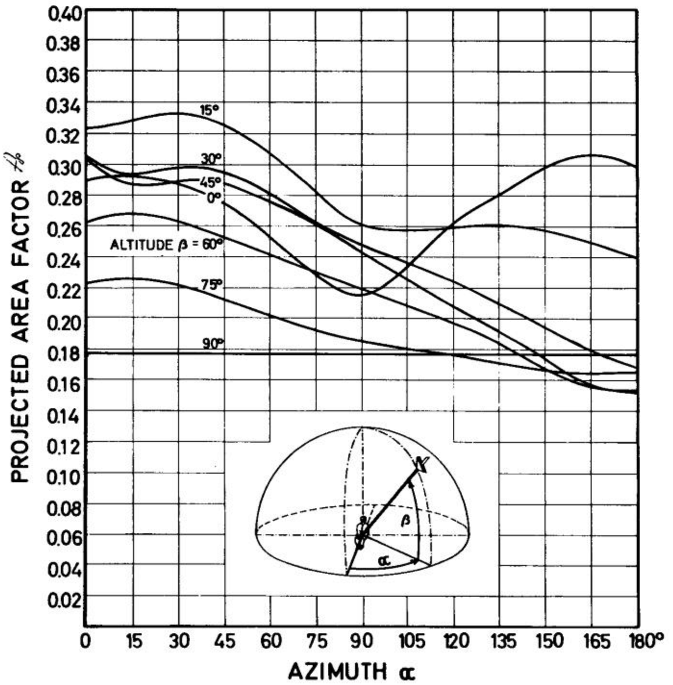

Figure 2. Projected area factor for sedentary persons, nude and clothed to an infinitely small surface (Fanger, 1972).

vertical rectangle is shown in figure 3. Since the figure shows the mean value for the person rotating around his own axis, only one diagram is necessary. If the orientation of the person has been fixed it will be necessary to use four diagrams.

6 PROJECTED AREA FACTOR FROM GEOMETRY AND NUMERICAL SIMULATION MODEL

In the last ten years computer animation programs have been developed for cinemas and computer games for which detailed 3D models have been developed for the human body geometry. This means that body posture can be generated in the general case from these software tools in order to make detailed modelling of the human radiation heat exchange with the surrounding surfaces. As a consequence of this, experimental investigation of the thermal radiation from the human body will be used less since the computerized models are superior. This will create a new world of investigations in which the possibilities are nearly unlimited.

In the paper (Kubaha et al., 2004) they made a detailed study for human projected area factors for detailed direct and diffuse solar radiation analysis using commercial software (Curious Labs, 2000) in which they modelled persons in standing or sedentary posture. The software was used to generate a detailed 3D model of the human body. The model of the human body was extremely detailed and consisted of 10,995 small surface elements, which made it possible to make a radiation simulation with sufficient details.

In order to compare the 3D geometry model with a simulation model – the human body was transformed to 3D humanoid geometries that were imported into a thermal analysis software package (ThermoAnalytics, 2001). The software uses ray tracing technique to predict the absorbed short-wave radiation energy for all the surface elements.

This method (Kubaha et al., 2004) gives the possibility for a detailed analysis of the human projected area factors. The authors made a verification and validation process in which they first verified the new 3D geometry model against simulation results from the thermal analysis software package (ThermoAnalytics, 2001). The comparison showed that the predictions with the 3D geometry model agreed well with the results of the ray tracing simulations in the whole range of angles for the azimuth *(α)* and altitude *(β)*. This comparison will not be described further in this paper since the importance in this matter is a calculation of the angle factor between the whole human body in a standing/sedentary position and the surrounding surfaces.

Since experimental data are only available for the whole body it is necessary, in order to make a comparison with these measurements, to make integration over the whole body surface for the 3D geometric model. Since Fanger (1970) produced the most experimental data with the best details these have been the best materials for the comparison. The validation shows that for the most altitude and azimuth angels the relative error has only been approximately five percent. The agreement has been good for both standing and sedentary postures, however for the sedentary posture the projected area factors were higher than ten percent relative error for an altitude angle of β = 15º and α < 60º / α > 300º.

One of the reasons for differences in results could be that the experiments were performed in a finite distance between the camera and the persons (7 m) – as opposed to the predicted results that were using an infinite distance between the radiant source and the human being, which resulted in parallel rays.

7 COMPARISONS OF RESULTS FOR ANGLE FACTORS

Since the results have shown such fine agreement comparing the two models developed by (Kubaha et al., 2004) with Fanger´s data (Fanger, 1972) it has been decided to use Fanger´s data in this study.

However, since the projected area factor for a seated person in figure 2 is depending on the angles α and β, it is necessary to go through an integration over the entire surface to find the angular factor.

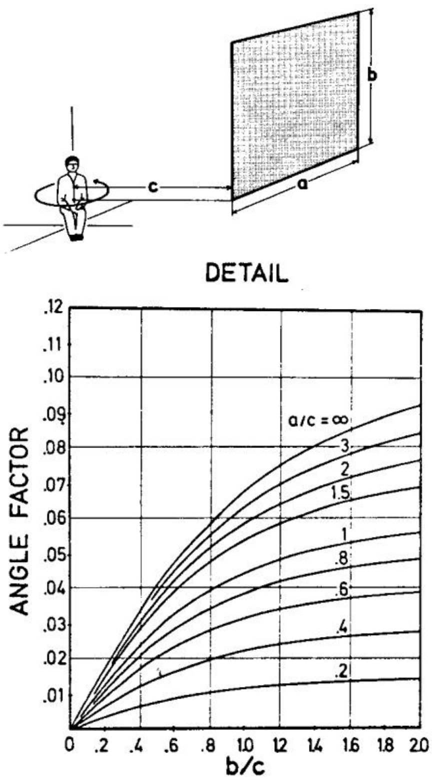

Figure 3. Mean value of angular factor between a sedentary person and a vertical surface when the person is rotated around a vertical axis. (Fanger, 1972).

Based on the data from figure 2 for a sedentary person and the equations (4), (5), (7) and (8) a model has been set up in the program MATLAB (version 7.5, 2007). In order to validate the model a comparison has been made with diagrams from Fanger (1972) for vertical and horizontal surfaces, where the angle factor has been found as a function of the two length relationships b/c and a/c, figures 1 and 3. In figure 3 is shown an example of the mean value of the angle factor between a sedentary human body and a vertical rectangle, where the person is rotating around his own axis.

In figure 4 there has been made a comparison between the calculated values by the author in MATLAB (the solid line) and the data from Fanger (1972) (the ◆- sign) for the angular factor between a sedentary person and a vertical surface in front of him.

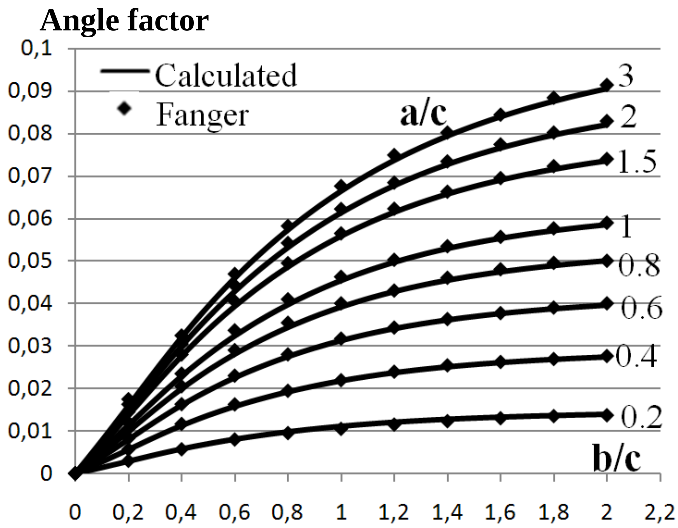

Figure 4. Comparison between the calculated values by the author in MATLAB (the solid line) and the data from Fanger (1972) (the ◆- sign) for the angular factor between a sedentary person and a vertical surface in front of him.

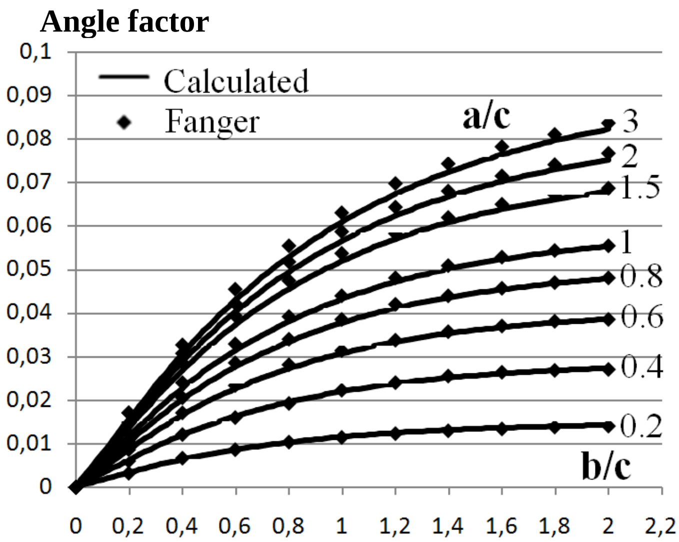

Figure 5. Comparison between the calculated values by the author in MATLAB (the solid line) and the data from Fanger (1972) (the ◆- sign) for the angular factor between a sedentary person and a vertical surface, when the person is rotated around a vertical axis.

tary person and a vertical surface in front of him. In figure 5 the same case has been shown for a case where the person is rotated around a vertical axis, analogue to the case shown in figure 3. Both cases shows very good concordant and indicate that the developed model can be used.

8 ANGLE FACTOR MODEL FOR SIMULATIOI PROGRAMME

In chapter 4 it was described how there will be 6 diagrams if the person is sitting in a specific position and only 2 diagrams if the person is rotating around himself, which will be simplifying the case. It is common to use the rotating model in practice in order to simplify the case for practical use. How important this influence is will be investigated before implementing the results in a computer analysis program for indoor climate and energy consumption.

In the case where the position is known but not the orientation, it is possible to use the general case where a person is rotating around his own axis. This will be a simplification since there will be only a need for two diagrams (1 horizontal, 1 vertical), where the actual values in a specific case can be found by a double linear interpolation. In the computer model the diagrams will be substituted by an analogue matrix for the corresponding values similar to shown in figure 5. This can be beneficially for this case since it is necessary to make an interpolation for the whole circle (in practice only the half - 180º). For the case with a specific orientation it might be an advantage to use the equations to calculate the specific angular factors. This method can also be used if the surfaces are tilted with other angels than horizontal or vertical.

Equation systems can then be created for the operative temperature for a general case. Real data for the specific case can be entered to calculate the thermal indoor climate, without having to spend time reading tables and making calculations. If the results show that the operative temperature under special winter conditions will be too low, the user can quickly make alternative calculations with other assumptions. For example, the glass in the window can be changed to a better quality with a lesser loss of heat. However the purpose for this paper is not to make a small program for analyzing a stationary situation but to implement the final model including more features in (BSim, 2005). By looking at different stationary results under different climate and building conditions it will be possible to get a good idea about what kind of features will be wanted.

As a platform for setting up the equations the program software (MATLAB version 7.5, 2007) has been used. It is the plan that – when the model has been created to the wanted form – the model can be rewritten to C++, which is being used in the BSim package. In this model other kinds of features have to be included in a more specific way in order to find the operative temperature depending on the location of the person in the room: direct solar radiation to a sedentary/standing human body, effect from shading devices, hot radiators, hot floor/roof, air velocity, etc.

9 EXAMPLE – AN APARTMENT WITH BIG GLASS AREAS

The finishing and sale of a couple of very mentioned buildings in Denmark have set new standards for how much glass you can use in a house facade. The technical development of windows with low U-values has made it possible to build houses with windows from floor to ceiling. However now architects and engineers are facing the fact that as the window areas get bigger it is increasingly more difficult to create fine overall solutions concerning the thermal indoor climate, energy consumption, sunshade devises, airing from open windows, furnishing possibilities, shielding against people looking in, etc. It is for sure that glass facades are here to stay because the Danes like the daylight, it is nevertheless important that experience from the first glass houses is being implemented and we shall see adjustments in buildings to come.

A way of presenting the problem of the importance of calculating the mean radiant temperature according to the actual location in the room, a new apartment, where there are windows from floor to ceiling in two facades in the drawing room, has been chosen, figure 6. The apartment is heated with floor heating. The glazed south façade is 4 m wide and the glazed west façade 6 m long, which give an area of 30 m^2 exposed to big glass areas. The room heights 2.6 m.

All the surfaces are internal except for the south- and west facing windows, where the glass in the windows are changed from, respectively, double glass (3.0 W/m^2 K), triple glass (2.0 W/m^2 K) and low energy triple glass (1.4 W/m^2 K). The outside temperature is fixed at -12 ºC and the inside air temperature as well as the temperature on the inside surfaces set to 21 ºC. The simulations in figure 7 and 8 have been done for a person situated in 5 different positions (1, 2, 3, 4, 5 and 6 m from south window) in a line 1 m parallel from the west window façade, figure 6 – the six vertical + to the left in the figure.

The results of the calculations of the mean radiant temperature have been shown on figure 7 and for the operative temperature on figure 8. Figures 7 and 8 show 3 pairs of curves for the three different kinds of glass types respectively, double glass (3.0 W/m^2 K), triple glass (2.0 W/m^2 K) and low energy triple glass (1.4 W/m^2 K). The mean radiant temperature and operative temperature respectively as 1) a func-

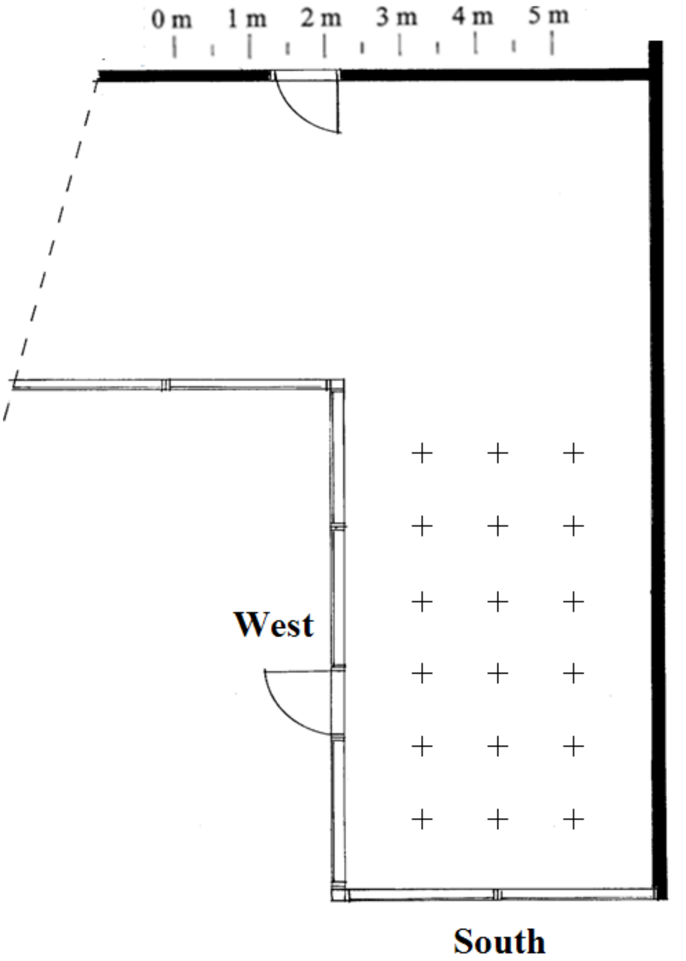

Figure 6. Modern south/west facing apartment with windows from floor to ceiling. The simulations have been done for a person situated in a line 1 m parallel and from the west window façade – the six vertical + to the left in the figure, figure 7 and 8.

tion of the distance from the south window and 2) an area weighted mean value independently of the distance – fixed value. As expected the mean radiant temperature is lower near both windows and increasing as the distance from the window is being increased, but never coming up to the area weighted mean value. Better U-value of the glass reduces the inconvenience from the cold radiation of the window. These results will give a more correct picture of the thermal condition in the room in which the location of the person has been taken into account. This is as opposed to what has been done in many programs for dynamic building thermal analysis, in which the mean radiant temperature has been calculated as an area weighted mean value independently of the location in the room – see the three curves with fixed values (horizontal curves). If a person is seated in the corner 1.0 m from a double glassed window the difference between the mean radiant temperature as function of distance (16.3ºC) and independently of the distance (17.9ºC) will be 1.6ºC. For the operative temperature the similar numbers will be (18.6ºC), (19.5ºC) and 0.9ºC, respectively. Better glass quality with higher U-value will decrease the differences.

In figure 9 the mean radiant temperature has been illustrated in a 3D landscaped form for a window

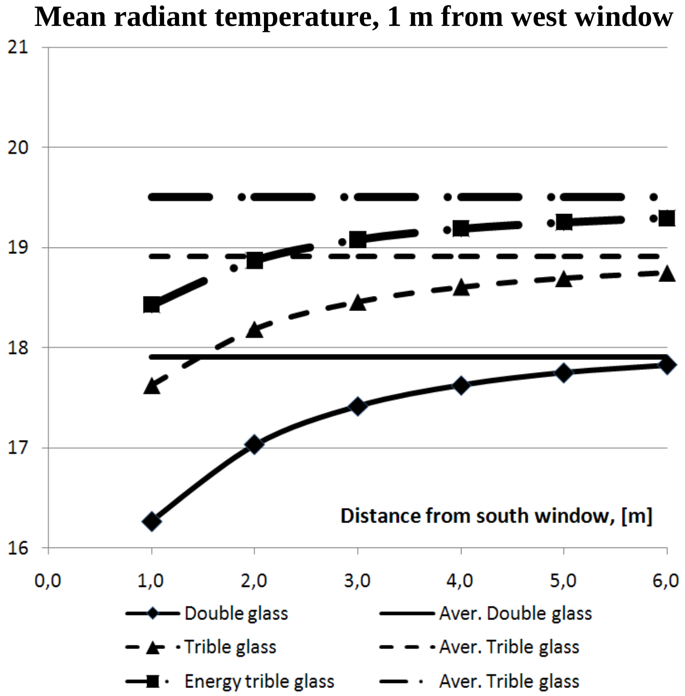

Figure 7. The mean radiant temperature 1 m from the west window as a function of the distance from the south window.

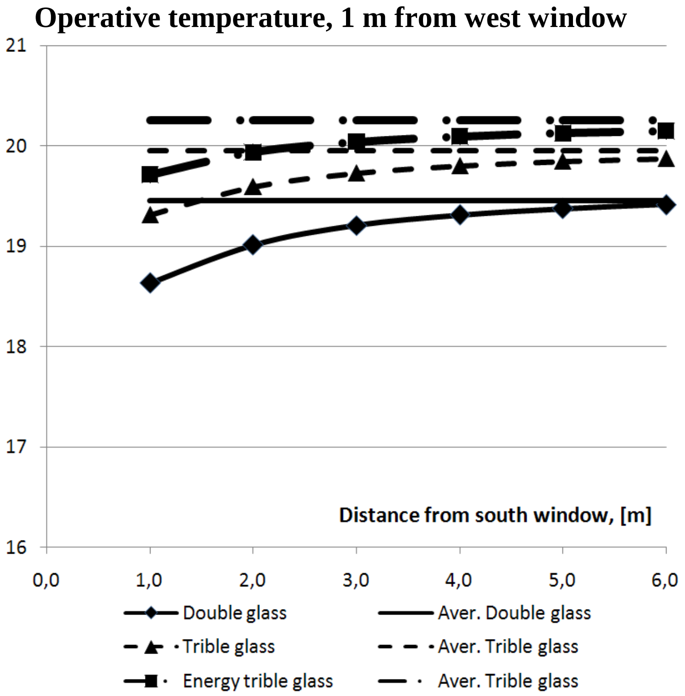

Figure 8. The operative temperature 1 m from the west window as a function of the distance from the south window.

with low energy triple glass. This figure illustrates how the temperature will vary around in the room compared to the mean radiant temperature as an area weighted mean value. This can be further developed to show the spatial distribution of comfort in the room in three levels: comfortable, just comfortable, and uncomfortable.

In practice it will be natural for people to have a higher air temperature in the room if they are situated nearby a cold window in order to compensate for being exposed to the inhomogeneous radiation and the lower operative temperature. As a result of

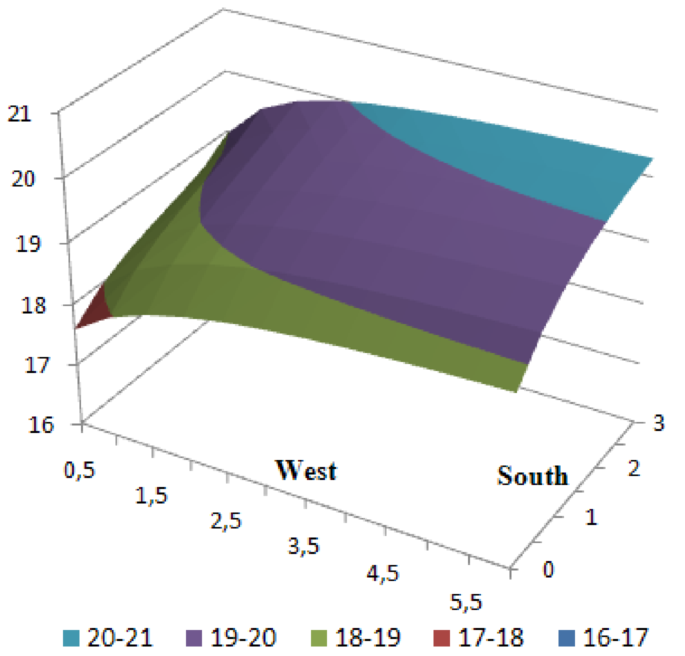

Figure 9. The mean radiant temperature illustrated in 3D landscape formed as a function of the distance from the west and south window for a low energy triple glass – see principle for grid in figure 6.

this the energy consumption for heating will be increased in order to keep satisfactory indoor thermal environment.

This problem could have been shown already in the design phase, if the simulation had taken into account the specific location of the person in the room. One can argue that this will complicate the calculations of the energy / thermal indoor climate too much, since the location will often be changed in the life time of the building. However it is natural for human beings to wish to sit nearby the window and have the view and daylight and if it is too cold the person can easily solve part of the problem by turning up the heat and by this way increase the air temperature. The individuals in the building will normally only have very little or no idea about the total heating demand in the building and will rather focus on their own personal comfort.

10 CONCLUSION

Since in the last decade there has been significant more use of glass facades in combination with development of new window types with very low U-values, the importance of a better model for calculation of the operative temperature and hence the mean radiant temperature has increased significantly. By setting up a better model for the radiant calculation it also opens up for a 3D illustration of the temperature distribution and the spatial distribution of comfort in the room.

It can be seen from the figures that the effect on the temperature in the room is more effected by a poor window construction, which is logical. On the other hand computer analysis programs are often used for convincing building owners that they should choose a better solution. In this aspects these calculations can be used as an important tool in the convincing process.

The paper shows a possible way to calculate the angular formula using data based on Fanger (Fanger, 1972) since the validation done by (Kubaha et al., 2004) has shown such fine agreement comparing the two models developed by (Kubaha et al., 2004) with Fanger´s data (Fanger, 1972). The model has been set up in the software (MATLAB version 7.5, 2007), which have shown to be a good platform for performing the necessary equations in the right order and built up knowledge on how the model is working. The model can later on be rewritten to for example to C++ and implemented to the BSim package. The model needs more development in order to take into account direct solar radiation through windows, airflow, PMV-values, etc. In addition the model will need more testing of other possible models for calculation of the angular factor.

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