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Considerations for occupant behaviour modelling in early design stages

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Abstract

This paper presents an ideal and worst case scenario approach for occupancy modelling in early design stages which can be used in building simulation. It defines the range of impact that occupant behaviour can have on comfort and energy performance in buildings, and can thus contribute to the decision making of architectural projects in early design stages.

Keywords: Occupant behaviour, building simulation, early design stages, comfort, energy performance

1 Introduction

In the context of the climate change, one research focus is to identify parameters that play an important role in the reduction of greenhouse gas emissions related to buildings. The behaviour of occupants in buildings is one of these parameters, and the lack of consideration of occupants in comfort and energy performance predictions has been identified as one reason why predicted and actual performance often deviate significantly.

Many studies are now trying to close this knowledge gap by attempting to translate the complexity of human behaviour into behavioural patterns which can then be represented by mathematical algorithms for use in calculations and simulations. One important question in this context is however, what level of resolution of these patterns and formulas is required for different stages of design. Very accurate monitoring of occupant behaviour in field studies can lead to very accurate algorithms, however these are most likely to be applicable only in contexts that are similar to the context of the original field study. Such an accurate approach is most useful for optimisation of existing buildings and in later design stages of a project when the all contextual parameters and project details are available. In early design stages however, where architects typically establish a hierarchy of design parameters, such contextual details are usually not yet known. It is the early design stages though, that offer the largest optimisation potential for greenhouse gas emissions and comfort.

This paper presents an ideal and worst case scenario approach for occupancy modelling in early design stages which can be used in building simulation. The approach presented should be viewed as an invitation for further discussion rather than a finalised proposal.

2. Influences on occupant behaviour as derived from the literature

The parameters below are discussed with particular focus on naturally ventilated buildings in early design stages. The discussion below is the summary of a more detailed literature investigation as indicated in the references.

2.1 Occupancy and use of office equipment

The schedule for occupancy in buildings has significant impact on the buildings energy consumption and it also defines the magnitude of internal heat loads, i.e. for how long office equipment is running. Typical occupancy schedules (Rubinstein et al. 2003) cover a period of 10–14 h which are equivalent to 6–8 h with 100% occupancy. The major influence that defines the occupancy schedule is the task that a person has to perform, and this also defines presence and absence patterns, the required office equipment (power of computer and monitor), as well as the intensity of use of this equipment (presence and absence from the computer/room).

2.2 Occupant controlled natural ventilation

Natural ventilation controlled by occupants via openable windows is influenced by a large variety of parameters related to the climate, the façade design, and the psychological or social environment (Ackerly et al 2011 , Burak Gunay et al 2013, Roetzel et al 2009).

Many window opening models have emerged out of field studies, and as pointed out by Ackerly et al, (Ackerly et al 2011) the literature agrees on the non-deterministic nature of window control. Apart from that the individual models differ significantly, and models intended for use in building simulation have become increasingly complex. Out of 10 different window opening models (Roetzel et al 2009), the adjustment parameters were (in order of occurrence in the models): outdoor temperature, indoor temperature, time of day/previous window opening angle, and with minor occurrences: occupancy, rain, indoor pollution, CO₂ concentration, occupant type (active/passive), and wind. It should be noted that most of these models are based on field studies in a moderate climate such as UK, Switzerland and Germany, with the exception of one model based on the Pakistani context.

In the development of window opening models there seems to be a trend towards an inclusion of more and interacting parameters to better reflect contextual influences. In early design stages, many of these parameters however are not yet known and the modelling should not be too time-consuming in order not to be an obstacle for investigation. Therefore a balance has to be found between the precision of many parameters and the simplicity of a few. The following can be summarized:

- Most recent window opening models agree that outside as well as indoor temperatures are the most crucial parameters. Especially in warm climates with a large diurnal swing this temperature difference is an important parameter.
- Time dependent models that correlate window operation with arrival or departure seem more suitable to moderate climates. In warm climates these patterns are likely to be superposed by temperature based window operating patterns, i.e. closure if outside temperatures exceeds the indoor temperatures.
- Most models considering the previous window state are based on window types which can have two states, closed and open, such as bottom hung windows which are common in Northern Europe. In warmer climates, window types seem to be more common which allow for larger opening areas as well as more adjustment opportunities such as sliding windows, side hung windows, and top hung windows which can be open, closed and allow for various opening angles. These window types

are not very well represented by models which only allow for the status 'open' or 'closed'.

- Wind, rain and other local climate characteristics have been mentioned in several studies as influential on window operation. However this impact is also dependent to the window type.
- The indoor air pollution as well as the CO₂ concentration in a room can have significant impact on the window operation by occupants, and it may override other criteria in severe cases.
- Night ventilation can significantly contribute to the cooling of a building, but in most cases it depends on the security policy whether or not windows can be left open at night.

2.3 Lighting control

Occupant controlled light switching is influenced by a large variety of parameters (Bordass et al 1993, Bourgeois 2005, Reinhart and Voss 2003, Galasiu and Veitch 2006, Moore et al 2003). Potential influences as derived from the above mentioned literature can be categorised as building related or occupant related. Building related influences are:

- Orientation and site context, i.e. exposure to direct vs. diffuse daylight, but this can be affected by blind control, too.
- Office type and number of occupants in the room, as well as the type of lighting system. E.g. for room related lighting the individual use of controls is likely to be lower the larger the number of people in the room. Switching by one individual might then affect the visual comfort of all others, and 'no change' could be the most likely common denominator.
- Location of controls, i.e. whether lighting can be controlled from each individual workplace or via a central switch at the door. If all occupants share one central switch, i.e. for room related lighting, then the use of the control is likely to be lower the larger the room size (distance to control unit, potential impact of change on other occupants).
- Distance of occupants from windows, i.e. a person who is placed further away from the façade is likely to activate the lighting earlier in the evening than someone closer to the façade where daylight levels are likely to be higher.

Individual influences on lighting control by occupants are:

- Task, i.e. how much time occupants spend working on a computer screen, since lower lighting levels tend to be acceptable for work on a screen (~300lux) compared to other tasks (500lux).
- Active or passive occupants, where active occupants adjust the lighting throughout the working day, whereas passive occupants tend not to change the lighting conditions during the day.
- Psychosocial influences such as cultural background, age, degree of fatigue. These parameters are based on individual preferences and expectations.

2.4 Blind control

Occupant controlled blind switching is another important parameter that affects a buildings comfort and energy consumption (Inkarojrit 2005, Rea 1984, Boubekri and Boyer 1992, Newsham 1994, Bulow-Hube 2000, Foster and Oreszczyn 2001, Osterhaus 2008, Sutter et al. 2006, Galasiu and Veitch 2006, Tuaycharoen and Tregenza 2007, Reinhart and Voss 2003). Since it influences the levels of daylight in the room it indirectly affects the artificial light switching patterns, too. As a result of the literature review, there is a difference between

active and passive users, passive occupants are keeping the blinds closed all day, whereas active occupants adjust the blinds according to glare and/or overheating.

The most important blind switching criteria are related to either glare, overheating or privacy. Overheating is related to the difference between indoor and outside temperature, and only at uncomfortably high indoor temperatures this is a likely reason for blind switching. Privacy as a reason for blind control is likely to lead to closure of blinds throughout the working day, i.e. in rooms that are particularly exposed so that occupants feel observed by others. Glare is a very complex blind switching criterion, that is influenced by a variety of parameters of which the following are the ones most mentioned in the literature:

- Orientation and sunlight penetration together with the distance of occupants from windows, i.e. the relationship of the sun angle within the field of vision of occupants.
- Window area of the façade and window arrangement, which impacts the luminance differences, but also depends on climate and external obstruction.
- Type of shading system, which predefines the balance of shading vs. daylighting.
- Task and quality of a computer screen, which can make a slight difference to the glare sensitivity of occupants if the task involves work on a computer.
- Visual and aesthetic interior qualities of the room, which has an impact on luminance contrasts and indirectly affects glare tolerance
- View quality, i.e. attractive views result in a higher tolerance to glare than less attractive views.

3. Evaluation of influences on occupant behaviour for modelling in early design stages

In the light of current efforts to reflect the behaviour of occupants in building simulation, the paragraphs above aim to summarize parameters that are relevant for occupant's behaviour related to occupancy and use of office equipment, natural ventilation, lighting control and blind control. The following paragraphs further examine the above mentioned parameters for their suitability to be used in an occupant behavioural model for building simulation in early design stages.

In early design stages of an architectural project, there is usually no budget and not enough time for a detailed investigation of the whole building context, in order to develop very accurate algorithms, and many parameters might not be known or available yet. A simplified method is therefore desirable, and a balance has to be found between the benefits of simplicity and the related sacrifice in accuracy. In terms of comfort and energy performance optimisation however, early design stages are crucial, and the fact that many parameters might not yet be known, also means that they can still be influenced towards comfort and sustainability.

Table 1 illustrates the influences on occupant behaviour that have been derived from the literature review above. It also shows an assessment of the significance of the criteria, 1 being parameters that are more likely to superpose others, and 2 being parameters which are potentially of similar importance but likely to be superposed by others. This assessment has been made based on experiences from the literature review. The last two columns indicate which of the investigated parameters are available in early design stages. This column basically differentiates between known, not known and optimisation potential. The latter are those parameters, which are not necessarily known or decided upon in early design stages. As such they represent an optimisation potential for early design stages. These are criteria which may still be influenced in order to improve comfort and energy performance in the building.

Table 1: Parameters influencing occupant behaviour, and evaluation of significance in early design stages

| Type of occupant control | Parameter | Sub parameter | Significance for comfort and energy performance Rating (1 = high, 2=medium / interdependent) | Known in early design stages? |
|-------------------------------------|-----------------------------------|--|---|---|
| Occupancy | Individual task / job description | Presence / absence patterns | 1 Significance increases the less people in an office (e.g. cellular) | x No, unless tenant is known |
| Use of office equipment | Individual task / job description | Type of office equipment | 1 Significance increases with intensity of use | x No, unless tenant is known |
| | | Intensity of use | 1 Major impact on internal heat loads | x No, unless tenant is known |
| Window control daytime / night time | Climate | Outside temperature | 1 Major impact, in combination with indoor temperatures | ✓ Yes (weather data) |
| | | Inside temperature | 1 Major impact, in combination with outdoor temperatures | ✓ Yes, Simulation output |
| | | Wind | 2 Impact depends on window type, orientation and climate | ✓ Yes (weather data) |
| | | Rain | 2 Impact depends on window type, orientation and climate | ✓ Yes (weather data) |
| | Façade design | Window type | 1 Defines air exchange rates and suggests control patterns, depending on size and placement | ✓ Optimisation potential, preferred type depends on climate and adjustability |
| | | Window size and placement | 1 Defines air exchange rates and suggests control patterns, depending on window type | ✓ Optimisation potential, different sized openings at different places |
| | Indoor environm. | Indoor air pollution / CO ₂ concentr. | 1 Can superpose opening pattern | x No |
| | Occupant | Time of the day (arrival, intermediate, departure) | 2 In warm climates likely to be superposed by temperature patterns | x No, unless tenant is known |
| | | Previous window state | 2 Depends on window type | x No, depends on window type |
| | | Psychosocial | 1 Large uncertainty | x No |

| | | | | | | |
|----------------------------------|---------------------------------------|--|--|---|--|---|
| | | influences | | based on individual preference and expectation | | |
| | Security (for night ventilation only) | Insurance policy | 2 | Will depend on façade and location | ✓ | Optimisation potential: early discussion with insurance |
| Lighting control | Individual influences | Task | 1 | Amount of time spent on computer screen | x | No, unless tenant is known |
| | | Active or passive | 1 | Affects frequency of switching | x | No |
| | | Psychosocial influences | 1 | Large uncertainty based on individual preference and expectation | x | No |
| | Building related influences | Orientation | 2 | Influence of direct sunlight, but likely to be superposed by blind control | ✓ | Optimisation potential, consider lighting together with shading |
| | | Office type, number of occupants in room | 1 | The larger the number of people the less likely individual action for room related lighting | ✓ | Yes or optimisation potential, task area lighting might be more useful in large rooms |
| | | Type of lighting system (task area or room lighting) | 1 | Impact for room lighting depends on number of people in room | ✓ | Optimisation potential, task area lighting preferred |
| | | Location of controls | 2 | Impact depends on room size | ✓ | Optimisation potential, ensure accessibility |
| Distance of occupant from window | | 1 | Impact increases with distance from window | ✓ | Optimisation potential, ensure daylighting in all spaces | |
| Blind control | Glare | Orientation, sunlight penetration | 1 | Sun angles predefine switching patterns | ✓ | Optimisation potential |
| | | Window area of façade | 2 | Impact depends on other factors e.g. climate, obstruction | ✓ | Optimisation potential |
| | | Window arrangements | 2 | Windows in view area are most influential | ✓ | Optimisation potential |
| | | Distance of occupant from window | 1 | In combination with orientation predefines switching patterns due to sun | ✓ | Optimisation potential |

| | | | | | |
|--------------|---|---|--|---|--|
| | | | angles | | |
| | Type of shading system | 1 | Impact on daylighting | ✓ | Optimisation potential, shading preferred that ensures daylighting |
| | Quality of computer screen | 2 | Little difference in case of full glare/disability glare | x | No |
| | Task | 1 | Amount of time spent on computer screen | x | No, unless tenant is known |
| | Visual and aesthetic interior qualities of the room | 2 | Impact on luminance contrasts and indirectly on glare tolerance | x | No |
| | Active or passive | 1 | Affects frequency of switching | x | No |
| | View quality | 2 | Indirect impact on glare tolerance | ✓ | Possibility to influence decision |
| Over-heating | Indoor temperature in relation to outside temperature | 1 | Influence stronger the higher indoor temperature | ✓ | Simulation output |
| privacy | Exposition of the room towards to outside environment | 1 | Influence stronger the more exposed the room is and the less occupants | ✓ | Possibility to influence decision |

In order to develop an occupant modelling approach for early design stages, at this stage of the parameter analysis the following considerations have been taken into account. The focus of comfort and energy performance modelling is typically the testing of different variations in order to support or discard design decisions. Many parameters are not yet known, so that input data cannot yet be obtained at a high level of precision. As a result of that the simulation results have to be evaluated as ballpark figures that incorporate a certain level of uncertainty. However, they are detailed enough to compare different variations. With this in mind, the development of an occupancy model for early design stages focuses primarily on those parameters in table 1 which have been identified as those who are likely to override other parameters.

Their potentials and limitations for modelling in early design stages and a proposal for an ideal and worst case scenario are further discussed below. The suggestions below are meant to be a starting point for further discussion and research and when applied to building simulation, they can be altered according to the project's requirements.

3.1 Use of office equipment

As identified in table 1 the two major parameters influencing the internal heat loads by office equipment are the type of equipment and the intensity of use. Both depend strongly on an

individual employee’s job description. I.e. an IT job would require a rather powerful set of office equipment running for the full day, while certain management jobs might require a lot of personal meetings but very little actual use of office equipment. Also the choice of office equipment becomes more significant the higher the intensity of use is. In any case, none of this information is likely to be known in early design stages of a project, and it may also change dramatically after e.g. a tenant change.

It can therefore be useful to define a set of different occupancy patterns which allow for testing of different configurations. One source for such patterns can be the Energy Calculator for PC Equipment (EU-Energy Star), which indicates appliances that meet certain standards regarding energy efficiency. It provides the power of different computer and monitor types in on, sleep and off mode, and suggests different types of use depending on how many hours of the day the chosen equipment is running in these three modes. In terms of energy consumption and thermal comfort predictions, an ideal and worst case scenario can be useful in early design stages. The use of a ‘worst case scenario’ with powerful equipment and high intensity of use can be a conservative estimate for the majority of other office tasks, and it allows for some latitude in case of a tenant change. The ideal case can then indicate the magnitude of optimisation potential related to office equipment. Not in all cases the full magnitude of optimisation will be realistic, but the ideal scenario could at least trigger a rethinking of common practice and raise the awareness of the impact of office equipment. A suggestion for the power consumption and usage pattern for such an ideal and worst case scenario is shown in table 2.

Table 2: ideal and worst case scenario for use of office equipment based on the Energy Calculator for PC equipment (EU-Energy Star)

| Ideal scenario, Electricity consumption per year: 21.4 kWh/year | | On | Sleep mode | Off mode |
|--|-----------------------|------|------------|----------|
| Usage pattern | Light office (h) | 2 | 9 | 13 |
| Equipment | Large notebook 17-18” | 25.5 | 1.7 | 0.9 |
| Worst case scenario, Electricity consumption per year: 580.3kWh/year | | On | Sleep mode | Off mode |
| Usage pattern | Busy office (h) | 8 | 2 | 14 |
| Equipment | Workstation (W) | 190 | 7.4 | 1.5 |
| | Top 27” LCD | 103 | 1.9 | 0.6 |

3.2 Occupancy

The presence and absence of occupants and related internal heat loads in offices are strongly depending on their task and the specific job description. Some tasks require constant presence in the office e.g. a processing task at the computer. Some other tasks, e.g. senior management or field staff are likely to spend a large amount of time outside the office, and in cases where the task requires constant customer contact, the number of occupants might be more than just the number of employees.

An ideal and worst case occupancy pattern should be consistent with the usage pattern for office equipment. The suggestion below is derived from the light and the busy usage pattern of the Energy Calculator for PC equipment (EU-Energy Star) mentioned above. The distribution of the ideal scenario is equivalent to 2 hours, and the worst case scenario to 8

hours full time occupancy per person and day, and both patterns are illustrated in figures 1 and 2.

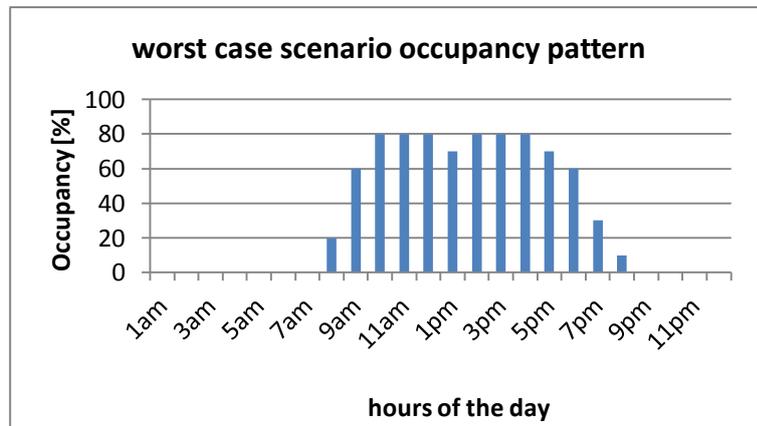


Figure 1: Occupancy pattern, worst case scenario

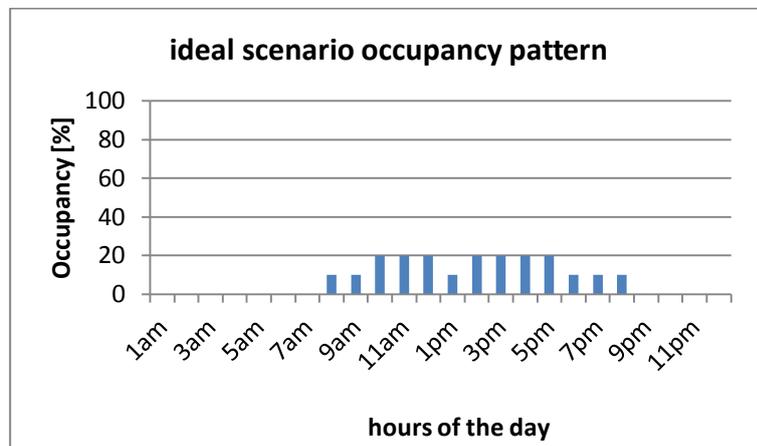


Figure 2: Occupancy pattern, ideal scenario

3.3 Window control day time

Occupant controlled window operation has been a focus of research in recent years, and from the literature review it can be observed that most studies agree on the importance of outside and indoor temperature as well as their difference. Outside temperature can be obtained from weather data sets or observations, and indoor temperatures can be obtained as output of thermal simulations.

Another parameter which is defined in table 1 as one which is likely to superpose others are window type, size, and placement in the façade (Roetzel et al 2009). Although research on this aspect is not as extensive as on temperatures so far, the impact is no less significant as these parameters predefine the air exchange rate, and suggest certain control patterns. In early design stages it is likely that these parameters are not yet completely specified. For this reason it will be difficult to incorporate this aspect into an occupant behavioural model for early design stages. However recommendations should be given at this stage that can help architects with the specification of the fenestration. Certain window types lead to higher air exchanges, other provide better weather protection, and different sizes might be useful for different seasons. In summary it can be stated that the more opportunities for adjustment are

provided, the more occupants will be likely to make full use of these window control opportunities.

High indoor air pollution or CO₂ concentration can easily override typical window opening patterns, however these parameters are not available in building simulation software such as EnergyPlus, and they are very difficult to predict in early design stages as they depend strongly on the materials of the interior fit out. Instead of consideration in the occupant behavioural model, recommendations should be given to carefully select the materials for the internal fit out in order to avoid negative effect on air pollution. Sufficient and accessible ventilation openings that suit the room size and the number of occupants in the room can also help to avoid high CO₂ concentrations.

Another parameter of importance which is too difficult to predict in early design stages is the cultural background, expectations and other psychosocial influences. However a recommendation can be given that the results of such a model should be evaluated with a certain level of uncertainty in mind.

Additional parameters which have been rated as those which can be superposed by others are wind and rain, time of the day and previous window state. The impact of wind and rain can be influential, however the magnitude of influence depends predominantly on the window type, the orientation of the façade and the whether there are dominant climatic phenomena. The time of the day (e.g. arrival, intermittent, departure) as a window operating criterion is in warm climates likely to be superposed by temperature patterns, i.e. the closure of windows due to outside heat at some stage during the day when the outside temperature exceeds the indoor temperature. The applicability of the previous window state depends on the window type, i.e. whether the opening is steplessly adjustable, whether it can be only open or closed, or whether there are more than those two predefined opening states.

It can be concluded that the predominant parameters which can be considered in an occupant behavioural model for early design stages are inside and outside temperatures. According to field studies, for occupant controlled natural ventilation the difference between active and passive occupants was not as strong as for lighting and blind switching and for this reason, the differentiation between an ideal and worst case scenario for daytime ventilation does not seem necessary.

As indicated in the literature review above, there are several algorithms available that define window opening patterns based on indoor and outside temperature, many of which take additional parameters into account as well. For early design stages, the most suitable one should be chosen depending on the climate and the context. The Humphreys adaptive algorithm (Rijal et al 2008) has the advantage that it only considers the indoor and outside temperature, and the resulting window opening probability can be translated into window opening angles for different window types (Roetzel et al 2011).

3.4 Night ventilation

Night ventilation is likely to be influenced by the same parameters as ventilation during day time. However the resulting opening pattern will be different, since it is mainly a decision made at the departure of occupants in the evening whether or not the window will be open all night until their arrival in the next morning. The predominant impact on night ventilation however is the window type and size as well as the placement in the façade. Often office buildings do have openable windows, but the security policy of the company does not allow

them to be open during night time, and often this is due to insurance reasons. Therefore again in early design stages, recommendations should be provided to architects to design burglary safe night ventilation openings. These can be developed in cooperation with an insurance company to provide a backup for a company policy.

In contrast to day time ventilation, where no ideal and worst case scenario seems obvious, for night ventilation this differentiation can be made. In an ideal case, night ventilation could be applied either consistently during the cooling season (which has to be determined individually for each climate) or initiated depending on the daytime window opening algorithm. For the worst case scenario, windows would be always closed during night time and no night ventilation would be possible.

3.5 Lighting control

The most influential parameters on lighting control as determined in table 1 are related to either the individual occupants or the building. On an individual basis it is important whether or not occupants spend most of the time at a computer, since in this case lower illuminance levels tend to be accepted. In early design stages none of this information is likely to be available. Psychosocial influences are important as well, such as age, degree of fatigue, and the literature review suggests a differentiation between active and passive light switching behaviour. Active users are adjusting the artificial lighting levels throughout the day, depending on daylight levels. Passive users however, were observed to leave the light on throughout the working day independent of daylight levels.

An additional significant influence on light switching is the type of the lighting system, which predefines a number of other influences. In case of room related lighting with a single control point (i.e. light switch at the door), it is the more likely that the light remains switched on all day, the more occupants are in the room since light on might be the common denominator. Also the distance of occupants from the façade is important since the person in the darkest area of the room is likely to require artificial lighting for longer periods of the day than occupants closer to the façade.

In early design stages, the future occupants of a building and related individual influences are often not yet known. Also building related influences will depend on the characteristics of the project, and are still likely to change. As such, any detailed modelling is very difficult throughout early design stages.

In summary it can be concluded, that an ideal and a worst case scenario for light switching represents the observations of active and passive behaviour, and the magnitude between both scenarios illustrates the uncertainty in occupant behaviour due to parameters which are not yet known in early design stages such as number of occupants and type of lighting system. An ideal scenario assumes light switching according to daylight availability, i.e. with a set point of 500 lux (or 300 for computer tasks). And the worst case scenario would assume the light to be switched on throughout the working day.

3.6 Blind control

The most influential parameters on blind control by occupants are related to glare, overheating and privacy (table 1), and as for lighting control the literature suggests a differentiation between active and passive occupants.

Although table 1 does not provide a complete list of parameters which affect the perception of glare, there is a large number of parameters which are influential and not all of them are easily measurable, such as the view quality or the visual and aesthetic interior qualities of the room. As indicated in the literature review glare is therefore very difficult to measure and in early design stages many influential parameters are not yet known.

One simplified index for glare evaluation is the Discomfort Glare Index (DGI) (Hopkinson 1970 and 1972) which only takes into account the luminance difference between the window and the surrounding background as seen from a reference point. It does not reflect the complexity of the perception of glare in real buildings, however in its simplicity it might be well suitable for early design stages and it is available in simulation software such as EnergyPlus. However one should be aware of the lower level of resolution of the results and factor this into the decision making based on a glare evaluation using the DGI.

Another influential parameter on blind switching is overheating protection, and depending on the climate zone this parameter will be most influential during cooling period of a building. Blind switching for overheating protection is likely to occur when the sun is shining on the façade, and the room temperature have reached the upper level of the comfort threshold. In a study in France, the threshold 200W/m^2 for solar radiation on the façade and a room temperature of 26 degrees Celsius was suggested (Sutter et al 2006). These thresholds might be adjusted for different climate depending on local specifications.

The third major influence on blind switching is related to a need for privacy by occupants. While in an existing building such behaviour might be observed in a field study, in early design stages there can only be an educated guess which rooms in a building should be flagged for the potential of blind closing due to privacy, since it also depends on the individual occupants. Typically it would be those which are very exposed to external or internal distractions, and these can range from visual distractions by passing traffic to psychological distractions by feeling observed by colleagues.

In early design stages, most of the influences on blind switching are not yet known, and as for light switching, a simplified approach based on an ideal and worst case scenario seems more appropriate. The worst case scenario would assume that blinds are closed throughout the working day, e.g. for privacy reasons or due to passive users. From a comfort and energy consumption point of view, this requires the artificial lighting system to be constantly switched on which increases the energy consumption as well as the internal heat loads. And an ideal scenario would assume that blinds switching is depending on either heat or glare, i.e. 'glare (DGI threshold)' or 'solar radiation on the façade + room temperatures above a defined threshold', whichever occurs first. Especially in office environments where work on computer screens can be expected, it is likely that glare is the more sensitive criterion compared to overheating. Glare tends to affect blind switching especially at low sun angles in the morning or evening, where overheating might be less dramatic. Also the switching behaviour will depend to some extent on the shading system itself and the control opportunities it offers.

4. Conclusions

Table 3 summarizes an ideal and worst case scenario approach to occupant behaviour modelling as explored in this paper. The magnitude of difference between both scenarios can help to evaluate the impact which occupants can have on comfort and energy performance in a particular building. The design recommendations can be indicative for architects and clients,

in order to achieve the configurations of an ideal scenario. This approach should be considered as an invitation for further discussion and further research, rather than a final proposal.

Table 3. Ideal and worst case scenario and design recommendations for occupant behaviour modelling in early design stages

| | Ideal scenario | Worst case scenario | Design recommendations |
|-----------------------------------|--|---|--|
| Office equipment (ref table 2) | Notebook, in on-mode for 2h per day = 21.4 kWh/year | Workstation in on-mode for 8h per day = 580.3kWh/year | - Use notebooks instead of desktop computers, where possible |
| Occupancy (ref figure 1 and 2) | 2h presence distributed over working time | 8h presence distributed over working time | - Avoid locating tasks that require powerful equipment in rooms which are exposed to solar radiation |
| Window opening daytime | <ul style="list-style-type: none"> - Any suitable algorithm which considers the relationship of outside and inside temperatures, e.g. Humphreys adaptive algorithm (Rijal et al 2008). - Potential for translation of window opening probability into window opening angles for specific window types according to (Roetzel et al. 2011) | | <ul style="list-style-type: none"> - Choice of window types considering air exchange rates, weather protection, + seasonal climate - Provision of sufficient and different sized ventilation openings in different parts of the façade. - Ventilation openings do not need to be windows - Choice of internal fit out considering room air quality - Dominant climatic phenomena at the location? - Consider uncertainty, due to psychosocial factors related to individual occupants. |
| Night ventilation | In combination with daytime window opening algorithm OR night ventilation during specified cooling season. | No night ventilation, windows always closed at night. | <ul style="list-style-type: none"> - Provision of burglary safe ventilation openings - Potential collaboration with insurance companies |
| Lighting control | Light switching according to daylight availability, i.e. set point 500 lux (or 300 for computer tasks) | Light switched on throughout the working day | <ul style="list-style-type: none"> - Consider occupancy sensors for large spaces with room related lighting (auto off) - Provide individual controls, i.e. switches/dimming where |

| | | | |
|---------------|--|---|--|
| | | | possible |
| Blind control | Blinds closed due to glare (DGI threshold)' OR 'solar radiation on the façade + room temperatures above a defined threshold '. | Blinds closed throughout the working day. | <ul style="list-style-type: none"> - Design spaces that provide a degree of privacy - Prefer shading systems which allow for daylight penetration when activated - Consider separate systems for heat or glare protection |

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