AN INVESTIGATION INTO THE ACHIEVABLE ENERGY SAVINGS PROVIDED BY LOW ENERGY LIGHTING SYSTEMS

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ABSTRACT

The energy consumption of buildings accounts for a significant amount of the total energy consumed by society. In the UK, domestic operational emissions currently accounts for over a quarter of the UK's total CO_2 emissions (ONS, 2008). Despite increasingly tougher legislation for building fabric performance unregulated appliance and lighting emissions have continued to rise in the UK (Boardman et al, 2005). Low energy lighting systems have the potential to provide significant energy savings in the building sector, yet realistic values for these energy savings are rarely defined.

This paper investigates the current low energy lighting systems within use in the industry with special attention to control systems and also the occupant evaluation of light frequency and temperature spectrums in low energy systems. A review of recent academic research and studies that have used both simulation and real models was undertaken in order to quantify typical energy savings relevant to the system type. Visual comfort factors in terms of levels of light frequency and the temperature spectrums were then assessed and determined relative to the corresponding low energy lighting system and the findings of the systems compared.

INTRODUCTION

Research undertaken by the Building Research Establishment (BRE) has shown that within the energy consumed by buildings, that which is required for electrical lighting and appliances accounts for 13% of the energy consumption of an average UK dwelling (Ni Riain et al., 2000). Previous research upon current low energy lighting systems has shown that considerable energy savings are possible when the correct system is matched to the required application and building environment (e.g. Li and Lam, 2003), however values of energy savings were found to vary significantly between studies.

Many forms of low energy lighting systems are available within the marketplace. However for any given application where a lighting system is required the choice of suitable system will be limited to only a few choices due to variable factors such as building occupancy, building orientation and available daylight illuminance for potential integration within the system. Furthermore the level of visual comfort provided to the occupants is paramount. Inferior visual comfort provided by an inappropriate lighting system may have many detrimental effects. The safety and productivity of the building occupants as well as the future widespread adoption of low energy lighting systems are all dependent upon the correct implementation and optimization of the current systems and hence the positive experiences of occupants combined with the energy savings provided.

The body of previous research into the area particularly when coupled with visual comfort considerations is limited and considerable inconsistencies exist within the calculated energy savings of each study. Evidently differing variables between these studies will result in different energy saving values being calculated however the magnitude of the differences is generally larger than would be expected. The rate of adoption of low energy lighting control systems by design teams is low and this can be attributed primarily to uncertainty in the achievable energy savings such systems provide. It is for this reason that this paper attempts to investigate the achievable energy savings of low energy lighting systems and the reasons for the inconsistencies in previous research. The method for such a study is concerned with a literature review of the applicable body of previous research, with the outcome of the paper considering the two building performance aspects of visual comfort and energy consumption due to lighting.

LIGHTING CONTROL SYSTEM VARIANTS

Lighting control systems come in many various forms and when utilised correctly have the potential to offer significant energy savings. However the success of an applied lighting control system is determined not only by the quantity of energy saved, but also the occupant's evaluation of the level of visual comfort provided by the system. Therefore a completely automatic system is not always the most suitable option, as control over ones owns environment is considered an important psychological factor in the feeling of comfort. The following section describes some typical forms of lighting control systems that are available and commonly used with the possible advantages and disadvantages of each in terms of user control and potential energy savings being considered.

Movement detection switching (MDS)

Through the use of infra red movement sensors lights are switched on or off dependent upon occupant movement. With such a system it is possible for the length of the time delay between switching off when no movement is detected to be adjusted. This adjustment is the only real level of control afforded to the occupants; even this is likely to be only accessible to certain individuals. In theory, this basic control system is capable of providing considerable energy savings; however, it would not be suitable for all environments. An example of an unsuitable environment would include areas where little movement of the present occupants takes place. The result of use in such an environment would be the annoyance of the lights being periodically turned off automatically. The likely result in such a situation would be the increasing of the time delay between on/off cycles or, potentially the complete bypassing of the system in favour of manual on/off controls. Both such measures would obviously greatly affect the energy savings achieved.

Movement detection dimming (MDD)

This type of system works on entirely the same principle as a MDS system, however as opposed to simply switching off when no movement is detected, the lamps will dim to a set percentage of the maximum flux capacity. Due to the dimming as opposed to simple on/off operation the energy saving potential is not as great as MDS systems, with the exact savings being highly dependent upon the chosen flux for dimmed operation.

Integrated daylight dimming systems (IDDS)

Such systems work on the principal of utilising the available daylight and only providing the “extra” required electrical lighting in order to obtain a set level of illuminance. In theory this principle results in zero wasted light due to the fact that only the required amount of electrical lighting is used, and therefore the potential energy savings are maximised. The system works through the use of photometric sensors that measure the “reflected illuminance of the plane located under them” (Roisin et al 2008). Direct occupant control in such a system is limited to adjusting the values of illuminance that the system is set to deliver, again this is likely to only be possible for occupants with access to the system controls. A secondary method of control is the possibility of occupants blocking daylight through the use of internal window blinds. This would result in an increase in the lamp light flux due to a decrease in the provided daylight illuminance. Such a measure is an unlikely occurrence due to the fact that research has shown an overwhelming preference for natural daylight when compared to electrical lighting” (Boyce, 2003). One such situation where the use of blinds is likely however is in the case of high levels of glare being caused by direct sunlight. The frequency of which such levels of glare would occur would be dependent upon the time of day, time of year, geographical location and the building orientation. Another factor that requires consideration in order for successful implementation is the likely reflection factor of the surfaces below the sensors. As these sensors measure the reflected illuminance, any surface with an extreme reflection factor is likely to result in distortion between the actual illuminance and the sensor reading. The outcome of such a situation would be either too great or too little lamp flux being provided. Hence the potential for both energy savings and occupant satisfaction would be significantly altered. When designing and implementing a low energy lighting control system that utilises motion or photometric sensors two further factors are of importance. These factors are the quantity and distribution of the sensors. Too few or poorly located sensors will likely result in inaccurate photometric measurements or “blind spots” in the case of motion sensors. Both would cause suboptimal levels of provided electrical lighting resulting in the dissatisfaction of building occupants. Conversely too many sensors will mean a decrease in the energy savings achieved. This is due to the fact that such sensors require power via a ballast or driver. Increasing the amount of sensors therefore increases the energy consumption.

DAYLIGHT DELIVERY SYSTEMS

One method of producing low energy lighting is to integrate the available natural daylight into the control system. Where as if purely daylight was used, the system would use zero energy, this is impractical in nearly all cases as the depth of most buildings would be too great for sufficient light penetration. The use of natural daylight is not purely advantages from an energy perspective. It is widely accepted that building occupants have a preference for natural daylight when compared with electrical lighting. The reason for such a preference has been the subject of significant studies (Galasiu and Veitch, 2006). These studies have considered daylight in the aspects of physics and psychology and how these aspects may differ from that of electrical lighting. As with electrical lighting “daylight is simply electromagnetic radiation in the wavelength range that is absorbed by the human eye” (Boyce, 2003). Where daylight differs from the overwhelming majority of electrical lighting systems is in the range of frequencies present in the light, and the fact that the spectral range will differ dependent upon environmental conditions and the time of both the day and the year. This is interesting from the point of view that in theory lighting control systems could be created which incorporate a shifting spectral range. This would in effect mimic this aspect of daylight. It is the author's opinion that any attempt to mimic the shifting spectral range of daylight, would either involve a large amount of effort which may not be justified in terms of improved occupant perception of electrical lighting, or would prove inferior due to the complex and random nature of daylight. Furthermore the energy implications could not be fully understood until such a system was created and analysed -either through field testing or the use of building performance simulation (BPS). A further factor that contributes to the preference of daylight is the psychological effect of windows. Windows provide a view out and psychologically enhance and expand a space. This has been shown to be valued highly by building occupants (Galasiu and Veitch 2006). The use of day lighting within a building requires careful planning by design teams, as many variables have the potential to cause discomfort to the occupants. Controlling of daylight will rely heavily upon typical values of available daylight; this factor will generally be linked to the geographical location more specifically the latitudinal location of the building. The aim when designing a daylight delivery system is to "harvest" as much of the available daylight as possible and to distribute it as evenly as possible within the space. On the other hand it is essential that glare and solar heat gains are controlled. Glare will cause visual discomfort and make it difficult for building occupants to effectively perform tasks. High solar thermal gains will not only be likely to cause thermal discomfort, but will also result in an increase of required cooling load during high temperature periods. This will subsequently increase the buildings energy consumption. It is the changing nature of each individual design scenario that means that each solution will be different and specific to each particular case. As such a number of products/solutions exist in the market place to perform the functions of collecting and distributing daylight as well as reducing glare and direct solar heat gains. When considering the distribution and quantity of daylight that a daylight delivery system will provide, the actual quantity will be heavily dependent upon the orientation, size and number of windows or window/wall ratio. The larger the window/wall ratio, the larger is the quantity of daylight that will be distributed within the building. The form of the windows and the depth of the room will effect the penetration and distribution within the space. Ideally rooms will have windows on more than one face; however this is not always possible due to the differing layout and size of buildings and the rooms within. Several techniques exist in order to maximise the potential light distribution in terms of both the distance from the source (window) and the even spread of the light. These include the position and form of the window in relation to the walls, for instance windows shallow in depth but large in width placed high up on the walls relative to the ground level of the room, will allow the light to reach a greater depth within the room. Such a window would sacrifice a quality view out that is so often desired by the occupants.

The use of light shelves provides one possible solution to the problem of distributing light. Light shelves work by reflecting the daylight upwards onto the ceiling of a room through the use of mirrors. Similarly anidolic concentrator's work on the same principle, reflecting light through the use of a parabolic mirror which concentrates the light and maximises the amount of light collected due to the reflective properties of a parabolic curve. The reflection factor of ceiling and wall coatings, as well as objects such as furniture within a room, can also greatly effect the light distribution -with higher reflective factors generally resulting in a greater distribution of the provided light. In summary, the designing of a suitable daylight delivery system requires the maximising of distributed daylight and the minimising of glare and solar heat gains. These two objectives are seemingly conflicting and as such, careful planning is required in order for a successful trade off between energy savings and visual comfort to be achieved.

SUMMARY LITERATURE REVIEW

A field study undertaken with the purpose of determining energy savings using an automatically controlled system, whilst also obtaining visual comfort in office lighting was performed (Onaygil and Guler 2003). The particular system used was an integrated daylight delivery system with continuous dimming. The room used was a fourth floor office in Istanbul, an area of high solar radiance. A potential flaw with the study was that the three windows each had a roller blind; however the central window was monitored for daylight illuminance by a horizontal photometric sensor. This in effect meant that the roller blind for the central window had to be constantly raised in order for the sensor to perform accurately; this would potentially be a source of glare that would reduce levels of visual comfort. (Atif and Galasiu 2003) performed a field test using an IDDS dimming and IDDS on/off in two separate atrium spaces in Canada. The aim of the test was to calculate energy saving values and to see if the systems were capable of performing in a real world retrofitted application, as opposed to either being designed at the same time as the building itself or ideal condition simulations. This study is unique when compared to the other studies researched during this project. This is due to the scale of the test area and the complex lighting in terms of lamp types and control. The on/off system consisted of 16, 150W incandescent lamps per floor over a three floor atrium, a total of 48. 8 of these lamps on each floor were continually on to provide adequate emergency lighting.

Additionally 8, 500W incandescent lamps were continually on, on the second floor and 10, 75W incandescent task lighting lamps were also continually on. This fact makes this test perhaps a more accurate assessment of potential energy savings using daylight control systems in existing buildings. Furthermore no attempt to enhance or alter reflective factors of walls, floors or ceilings was made; this enhances the validity of the testing conditions as a retrofit scenario. (Roisin et al 2008) conducted a comprehensive study of potential energy savings using the simulation program DAYSIM to simulate daylight conditions. Occupancy levels were also included within the study. Three low energy systems were assessed, IDDS, MDD and MDS plus the combinations of IDDS/MDD and IDDS/MDS. Each system combination was assessed in the four orientations of North, South, West and East and at three locations Brussels, Athens and Stockholm. These locations were chosen for their varying average levels of daylight illuminance and were intended to represent high, medium and low levels. Simulation of a full year was performed for each location, system and orientation. During the simulation the issue of occupant control was neglected, as was the likely occurrence of glare during operating hours which would alter both energy savings and visual comfort. It is important to be aware that the reference case against which energy savings were calculated assumes that lights are continually on in the case of occupancy, and lights off in the case of occupant absence. This would be unlikely to be the case in a real scenario and would have effected the calculated values of energy consumption and hence energy savings. Even with potential discrepancies taken into account, the annual energy savings are significant, ranging between a minimum of 45% to a maximum of 63% for IDDS based operations. The effects of occupant behaviour on energy savings of lighting control systems have been considered in a limited number of studies. (Bourgeois et al 2006) conducted such a study considering the advanced occupant behavioural modelling within energy simulation programs and how improved behavioural modelling affected the energy savings for both manual and automatic lighting control systems. Most research assumes a reference case where lights are on during occupancy or off during occupant absence. Such simplified reference cases inevitably result in inflated values of energy savings when the reference is compared to an automatic system. The study also included the effect on cooling and heating loads due to occupancy levels and solar heat gains. A sub hourly occupancy based control model (SHOCC) which was coupled with lightswitch 2002 algorithms for lighting simulation and with ESP'r for whole energy simulation (cooling and heating loads). It is beyond the scope of this project to analyse the SHOCC, however it was shown to provide a more accurate behavioural model than when compared to diversity factors that are more generally used to predict and model occupant behaviour.

Visual comfort

Throughout this paper, comfort is continually considered when investigating previous research, analysing energy saving potential and considering the types of low energy lighting control systems. Quantifying visual comfort for each individual study has not proved to be possible due to a lack of relevant data. Visual comfort is subjective and as such is difficult to measure as different occupants will have differing perceptions of their environment. When design teams consider all aspects of occupant comfort, the aim is to please most of the occupants most of the time, to please all occupants would be an impossible task. This section looks at the factors of visual comfort considered by design teams. The approach adopted by most design teams is to consider visual comfort to simply mean an absence of visual discomfort (Boyce 2003). Glare, uniformity and illuminance are the main aspects considered when attempting to eliminate visual discomfort during the design of a lighting system. Illuminance is defined as the total luminance per unit area. The unit of illuminance is lumens/m2 more commonly referred to as lux. When considering illuminance the tasks which are likely to be performed within the room have a considerable impact upon the recommended levels of illuminance, for instance BSRIA rule of thumb guide recommends illuminance levels of 300-500 lux for general offices and 50-100 lux for hotel bedrooms (Pennycook 2003). This difference is considerable but both are justified due to the tasks performed in the relevant rooms. It is such guidelines that design teams will adhere to in order to eliminate the possibility of visual discomfort within a room. Uniformity of light can cause visual discomfort if the light is either too uniform or not uniform enough. Uniformity is required in order for tasks areas to be well lit and to prevent stark differences in illuminance levels, which would cause high levels of distraction to building occupants particularly in peripheral vision. When design teams consider uniformity of illuminance, manufacturer's guidelines are usually followed during design. This is due to the fact that different luminaires will distribute the available luminance differently dependent upon the type of luminaire, and the particular lighting application for which it is required. Glare can be described as an extreme case of non-uniformity (Boyce 2003), or in other words a specific area of high illuminance, this is liable to cause significant discomfort for building occupants. The potential for glare to occur from electrical lighting is generally considered to be eliminated by the use of a luminaire suitable for the application. A suitable luminaire will distribute the available luminance in a manner that will prevent glare from occurring. Where glare poses a real possibility is from direct sunlight entering a space through windows. Methods adopted by design teams to combat such scenarios include daylight shading systems, the use of glazing with high reflectance, and the inclusion of window blinds. Even when these methods are used the changing nature of the available daylight will mean that the occasional occurrence of glare cannot be completely dismissed. A further factor when considering comfort is the level of control afforded to occupants. This can be in the form of manual lighting control, manual blind control or the ability to adjust illuminance set points within automatic systems.

Analysis of energy savings

It was the original aim of this paper to study a wide range of different low energy lighting systems, however having investigated the area it is clear that the majority of academic research is concerned with day lighting systems. This is understandable when the achievable energy savings of day lighting systems are compared to those systems which do not utilise or integrate daylight. Table 1 shows all the control systems cases investigated during the project in terms of commonly occurring variables and energy savings as well as visual comfort considerations. As can be seen the majority of the systems are IDDS variants, the calculated or measured energy savings vary significantly. From the simulated studies using BPS the energy savings vary from 8.7% (cases 12, 17 and 22) for an MDD system to 90% (case 9) for IDDS with dimming and MDD system. This may be considered an unfair comparison due to the differences of two different system types, however comparison between only the IDDS based systems under simulation shows a minimum annual energy saving value of 50% (case 11), compared to a maximum annual energy saving of 90% (case 9). This 40% difference shows that considerable inconsistencies are present between simulated studies. Even when all the different variables are considered, such a vast difference seems an inflated figure to that which may realistically be expected. From the field studies which consist of entirely IDDS systems, considerable variations in energy savings are still found. The minimum values being 11 -17% (case 8) for an IDDS on/off system compared to a maximum of 69% (case 2) for an IDDS with dimming system. Case 4 shows greater energy saving potential (80%) but this value is for only 80% of the year and due to the lack of available data any estimates concerning annual savings would be likely to be of little academic worth and have therefore been neglected from consideration. When comparing like for like systems and their calculated energy savings, field studies tend to show similar inconsistency when compared to simulation studies. Minimum energy savings for IDDS with dimming were found to be 20-23% (case 5) with maximum energy savings of 69% (case 2).

DISCUSSION

Although energy saving values between the studies vary significantly the order of the mean values compared to the system type are as would be expected. IDDS with dimming / MDS showed the highest mean energy savings with a value of 67%, where as IDDS dimming / MDD shows a mean energy saving of 54%, and IDDS dimming 48.7%. IDDS on/off is only included in one of the studies considered with a value of 14%, although it would be expected that such a system would provide less energy savings than an IDDS dimming based system the magnitude of the difference is larger than may be expected. This is likely due to the fact that the study from which the value was obtained used incandescent lamps with over half of which being continually switched on to provide emergency lighting. This obviously had a considerable effect upon the energy saving potential of the system. Latitude can be considered a good approximate indication of the available levels of daylight illuminance and as such it would be expected that a distinct correlation between latitude and annual energy savings would exist- with the lower the latitude the higher the energy savings. This proved not to be the case, the reason for which can be attributed to a combination of inconsistency and the inclusion of differing variables between studies. Annual savings dependent upon glazing orientation are of interest in order to establish which orientation is likely to produce the highest energy savings. It was expected that south orientated glazing would produce high energy savings and this is confirmed with a mean value of 56.25%. It is important however to be aware that of the 12 south orientated cases considered 10 were produced during the same study and therefore the consistency of values is improved. A lack of significant quantities of data for all other orientations makes the possibility of comparison limited, as potential anomalies would have a magnified effect upon the comparison due to the limited quantity of data

Quantitative analysis of the qualitative visual comfort aspects of the studies considered is difficult, due to the fact that few of the papers have explicitly considered visual comfort outside of reasonable levels of illuminance and uniformity. With insignificant amounts of quantitative data any analysis of such would be highly speculative

CONCLUSION AND FUTURE WORK

This project has considered the energy savings potential of the common low energy lighting control systems. The majority of the systems considered were IDDS of various forms. Energy savings were found to vary considerably between studies. This can be attributed to the large quantity of differing variables and constraints within each study. Furthermore only one of the cases considered incorporated the energy implications associated with differing heating / cooling loads caused by solar heat gains through the use of daylight integrated lighting. The study in question (Bourgeois et al 2006) showed that in reality the savings potential of day lighting systems is generally less than considered by other studies when cooling / heating load is taken into account, although the available savings are still sufficient to justify the use of day lighting systems. The need for further research is evident as the number of available studies considering energy savings are limited at the present time. This is likely to be due to the level of maturity of the area in question and the long duration of each study, often in excess of a year. If / when a larger body of research is undertaken more meaningful comparisons of energy savings will be possible. In order for accurate comparisons of research future studies would ideally include common and controlled variables and consider the energy implications of annual heating / cooling loads. Such an approach to future research would allow for the different variables to be weighted according to the magnitude by which they affect the final energy savings. This would be with the resulting aim being the ability for design teams to make informed choices during design. This coupled with further development in the simplified method of predicting energy savings in day lighting systems (Ihm et al 2009) would increase the attractiveness of day lighting systems. In turn this would mean improved adoption rates by design teams resulting in energy savings worldwide. Furthermore the continual development of low energy lamps and solid state lighting is liable to further increase energy savings as the technologies are improved and developed in order to be suitable for more traditional lighting application.

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Table 1
Energy savings and variables for all cases considered

Paper	Date	Author(s)	Case	System type	Mean annual energy savings	Location	Latitude	Longitude	Simulation or Field test	Total Window Area m²	Window transmittance	Window orientation	Floor area m²	Perimeter area	Lamp Type	Illuminance set point	Comfort considerations	Sensors
Determination of the energy savings by daylight responsive lighting control systems with an example from Istanbul	2003	Onaygil S. & Guler O.	1	IDDS with dimming (3-100%)	33.25%	Istanbul	40° 58' N	29° 05' E	Field	3.03	0.57*	North-East	21	21	Fluorescent 58W 6 Luminaires 2 Lamps per Luminaire	500 Lux	Manual override control High Uniformity High Brightness Manual Blinds	10
An analysis of lighting energy savings and switching frequency for a daylit corridor under various indoor illuminance levels	2002	Li D. & Lam J.	2	IDDS with dimming (1-100%)	68%	Hong Kong	22° 20' N	114° 11' E	Field	48.5	0.23	North-West	52.2	52.2	Fluorescent 36W 12 Luminaires 2 Lamps per Luminaire	450 Lux for four months reduced in 50 Lux increments every week thereafter until 200 Lux	High Brightness High Uniformity	1
Measured energy savings due to photocell control of individual luminaires	1998	Knight I.	3	IDDS stepped (0,75,100%)	10-15% for 90% of year 30-50% for remaining 10% of year	Cardiff	51° 42' N	3° 21' W	Field	Unspecified	Unspecified	Unspecified	Unspecified	Unspecified	Fluorescent 36W 12 Luminaires 2 Lamps per Luminaire	600 Lux	High Brightness	8
			4	IDDS with dimming (3-100%)*	80% for 80% of the year	Cardiff	51° 42' N	3° 21' W	Field	Unspecified	Unspecified	Unspecified	Unspecified	Unspecified	Fluorescent 36W 12 Luminaires 2 lamps per Luminaire	360 Lux	High Brightness	8
The New York Headquarters daylighting mockup: Monitored performance of the daylighting control system	2006	Lee E. & Selkowitz S.	5	IDDS with dimming (35-100%)	20-23%	New York (Manhattan)	40° 46' N	73° 59' W	Field	37.2	0.75	West 118.7° of true South	200.5	200.5	Fluorescent 17W 2 Lamps per Luminaire	400 Lux	Shading High Brightness	7
			6	IDDS with dimming (35-100%)	52-59%	New York (Manhattan)	40° 46' N	73° 59' W	Field	79.2	0.75	South and West Corner 28.7° and 118.7° of true South respectively	200.5	200.5		400 Lux		7
Energy performance of daylight-linked automatic lighting control systems in large atrium spaces: Report on two field-monitored case studies	2003	Atif R. & Galasiu D.	7	IDDS with dimming (20-100%)	46%	Quebec	46° 48' N	71° 23' W	Field	Unspecified Large (Estimate?)	0.03 - 0.15	West and East	1300 & 2000 surrounding walkways	1300?	Fluorescent 40W 646 Lamps	200 Lux	Reasonable Brightness	20
			8	IDDS on/off	11-17%	Ottawa	45° 20' N	75° 43' W	Field	Unspecified Large (Estimate?)	0.18 - 0.41	All orientations	151	151	Incandescent 150W 18 per floor, 48 total 0 on each floor on constantly as emergency lighting Incandescent 500W 8 in total Incandescent 75W 10 in total constantly on	200 Lux	Reasonable Brightness	1
Adding advanced behavioural models in whole building energy simulation: A study on the total energy impact of manual and automated lighting control	2002	Bourgeois et al	9	IDDS with dimming & MDS (3-100%)*	90%	Rome	41° 54' N	12° 30' E	Simulation	1.68 assuming 1m width	0.69	South	5 wide depth not specified	10 plus depth	Fluorescent	600 Lux	High Brightness High Uniformity	Unspecified
			10	IDDS with dimming and MDS (3-100%)*	77%	Quebec	46° 48' N	71° 23' W	Simulation	1.68 assuming 1m width	0.69	South	5 wide depth not specified	10 plus depth	Fluorescent	600 Lux	High Brightness High Uniformity	Unspecified
Lighting energy savings in offices using different control systems and their real consumption	2008	Roisin et al	11	IDDS with dimming (3-100%)	50%	Stockholm	59° 20' N	18° 03' E	Simulation	3.1	0.77	South (although all 4 orientations were assessed South is shown to limit the ammount of data from one study	20	20	Fluorescent	500 Lux	High Brightness High Uniformity	Unspecified
			12	MDD (3-100%)	8.70%	Stockholm	59° 20' N	18° 03' E	Simulation	3.1	0.77	South	20	20	Fluorescent	600 Lux	High Brightness High Uniformity	Unspecified
			13	MDS on/off	11%	Stockholm	59° 20' N	18° 03' E	Simulation	3.1	0.77	South	20	20	Fluorescent	500 Lux	High Brightness High Uniformity	Unspecified
			14	IDDS and MDD (3-100%)	51%	Stockholm	59° 20' N	18° 03' E	Simulation	3.1	0.77	South	20	20	Fluorescent	500 Lux	High Brightness High Uniformity	Unspecified
			15	IDDS and MDS (0-100%)	53%	Stockholm	59° 20' N	18° 03' E	Simulation	3.1	0.77	South	20	20	Fluorescent	500 Lux	High Brightness High Uniformity	Unspecified
			16	IDDS with dimming (3-100%)	53%	Brussels	50° 46' N	4° 32' E	Simulation	3.1	0.77	South	20	20	Fluorescent	500 Lux	High Brightness High Uniformity	Unspecified
			17	MDD (3-100%)	8.70%	Brussels	50° 46' N	4° 32' E	Simulation	3.1	0.77	South	20	20	Fluorescent	600 Lux	High Brightness High Uniformity	Unspecified
			18	MDS on/off	11%	Brussels	50° 46' N	4° 32' E	Simulation	3.1	0.77	South	20	20	Fluorescent	600 Lux	High Brightness High Uniformity	Unspecified
			19	IDDS and MDD (3-100%)	54%	Brussels	50° 46' N	4° 32' E	Simulation	3.1	0.77	South	20	20	Fluorescent	600 Lux	High Brightness High Uniformity	Unspecified
			20	IDDS and MDS (0-100%)	56%	Brussels	50° 46' N	4° 32' E	Simulation	3.1	0.77	South	20	20	Fluorescent	500 Lux	High Brightness High Uniformity	Unspecified
			21	IDDS with dimming (3-100%)	61%	Athens	37° 54' N	23° 44' E	Simulation	3.1	0.77	South	20	20	Fluorescent	500 Lux	High Brightness High Uniformity	Unspecified
			22	MDD (3-100%)	8.70%	Athens	37° 54' N	23° 44' E	Simulation	3.1	0.77	South	20	20	Fluorescent	500 Lux	High Brightness High Uniformity	Unspecified
			23	MDS on/off	11%	Athens	37° 54' N	23° 44' E	Simulation	3.1	0.77	South	20	20	Fluorescent	500 Lux	High Brightness High Uniformity	Unspecified
			24	IDDS and MDD (3-100%)	57%	Athens	37° 54' N	23° 44' E	Simulation	3.1	0.77	South	20	20	Fluorescent	500 Lux	High Brightness High Uniformity	Unspecified
			25	IDDS and MDS (0-100%)	59%	Athens	37° 54' N	23° 44' E	Simulation	3.1	0.77	South	20	20	Fluorescent	600 Lux	High Brightness High Uniformity	Unspecified