Simulation of daylight and artificial lighting integration and energy savings

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ABSTRACT

This paper aims to find out integrated lighting simulation, the contributions from both the daylighting system and from the artificial lighting system are simultaneously taken into account. The concept behind this integrating lighting system is that the light output of individual luminaire mounted over a region of working plane is to be controlled according to the available daylight in that particular region. Any luminaire can be kept off when daylight is sufficient or can be operated at different dimming level and even at full glow when available daylight is less or insignificant. The adequacy of daylight availability is judged on the basis of desired average illuminance level on working plane. Here simulation is done using MATLAB coding. This paper provides information on daylight availability and the dimming levels of all artificial light sources which are set accordingly so that contribution from artificial lighting system together with available daylight meets desired lighting level and uniformity. These are demonstrated by isolux diagram and illuminance distribution for winter with north facing window orientation and local time 12 noon. Data base is generated for eight different window orientations, five local times for winter for corresponding CIE (International Commission on Illumination) SSLD (Standard Sky Luminance Distribution) identified for Roorkee.

Keywords: Integrated Lighting Simulation, Uniformity of Illuminance, Dimming Value, Isolux Diagram, Lighting-Load, Average Illuminance.

1. INTRODUCTION

Prediction of daylight availability in an interior space at different seasons throughout a year is important for daylighting design. This prediction of daylight availability is made either in absolute illuminance or in relative illuminance with respect to external illuminance. In either case sky luminance distribution model or data is required. CIE (International Commission on Illumination) proposed its homogeneous sky types with the understanding that the 15 sky luminance distributions represent the sky type at any location all over the world for different seasons. Out of 15 sky types, five types represent overcast skies, five types represent intermediate skies and the rest five types represent clear skies [1]. Attempts have been made earlier to utilize CIE 15 General Sky models for daylight predictions [2] and also to correlate these Standard models with measured sky luminance data [3]. So, to utilize the CIE Standard general sky model for the prediction of daylight illuminance at a particular location, the relevant sky type representing the prevailing sky luminance distribution for different seasons throughout the year must be known. Daylight Coefficient (DC) technique is the commonly used tool for daylighting design using sky luminance distribution [4,5,7]. Under IDMP (International Daylight Measurement Program) monthly average hourly sky luminance distribution data was available in India at Roorkee (latitude 290 51' (N), longitude (E)

77053') at three different seasonal conditions-summer solstices, winter solstice and equinox [6]. With the help of these data and DC method sky types of Roorkee are identified for three different seasons [8]. With the identified sky the amount of available daylight on the horizontal working plane of the simulated room is being calculated [9,10,11,12]. In the integrated lighting simulation, the contributions from both the daylighting system and from the artificial lighting system are simultaneously taken into account. Some steps are followed to do the total simulation. In the first step using Matlab program, the distribution of daylight illuminance on the working plane is to be recorded for particular time, season and sky type. In the second step on the basis of daylight availability from isolux diagram, the required extra illuminance value is obtained to achieve the desired illuminance value on the working plane. It also indicates the different dimming levels of artificial luminaire depending upon their respective positions, e.g. all the artificial luminaires situated near the window can be switched off (100% dimming); on the other hand, those situated at the far end of window is to be set at full glow (0%dimming). The luminaires situated at the intermediate positions are to be set at suitable intermediate dimming levels. In the third step, program is run to get the effect of integrated lighting system on the working plane. At this stage, it needs to check whether desired light level and uniformity on working plane is achieved or not. In case of noncompliance of light

distribution, we need to go back to second step to adjust dimming levels.

Computation Block diagram of integrated lighting simulation.

The grid specific integrated illuminance (block 3) is the sum of illuminance values due to grid specific artificial lighting system (block 1) and daylighting system (block 2). This is explained by the block diagram as shown in Figure 1.
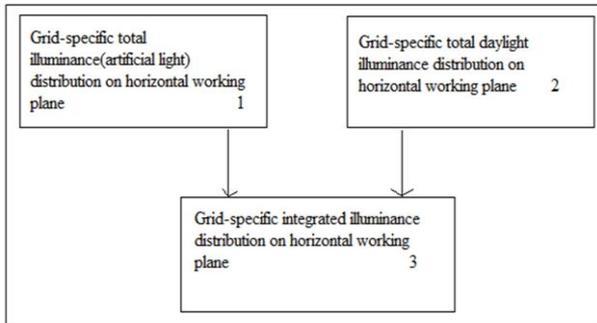

Figure 1. Computation block diagram for integrated lighting

2. CASE STUDY

. In this case study, a room of following specifications is considered for dynamic simulation.

- Room dimension. 6m*5m*3m
- Window dimension. Window area equals to 20% of floor area ($30m^2$) is taken.
- W_h (window height)=1.5m (fixed).
- Width of window area. 4m.
- Ceiling, wall and floor reflectance. 60%, 60% and 10%.
- Glazing material. Oceanic blue.
- Working plane height. 0.80m (fixed).
- Window sill height. 1.0m (fixed).
- Window orientation. 0^0(North) to 315^0(NW) at an interval of 45^0.

Sky type 15(VI.6) prevails in Roorkee during summer and equinox and sky type11 (IV.4) prevails in winter **[8]**. Keeping the identified sky type fixed, the variation of sky luminance pattern is considered taking different local time and corresponding zenith luminance (L_z).

Other following variables are taken in this simulation-
Location. Roorkee [$29^051'$ N; $77^053'$ E]
Local time. 8am, 10am, 12noon, 2pm and 4pm.
Day number. J=15(winter); J=74(Equinox); J=166(summer)

The following design parameters are set to evaluate the integrated lighting simulation for different local time for eight window orientations for winter
i)   Average maintained illuminance and
ii)   Uniformity of illuminance on the entire working plane.
iii) Lighting load with dimming and
iv)   % Lighting load reduction with respect to full load

The expected grid-specific E_{avg} on this working plane is set to a value $\geq$500Lux and overall uniformity $U_o \sim 0.6$. To fulfil this target, the corresponding deficiency of daylight on the specific grid position of the working plane is compensated by adjusting the dimming value of the nine luminaires situated over those grids. Daylight isolux diagrams for a particular

season and north window orientation provide an idea regarding the availability of daylight on the working plane due to direct and interreflected contribution of daylight. This diagram and point-specific lux values guide to set dimming values of 9 luminaires.

The layout of luminaires and grid points are shown in Figure 2.
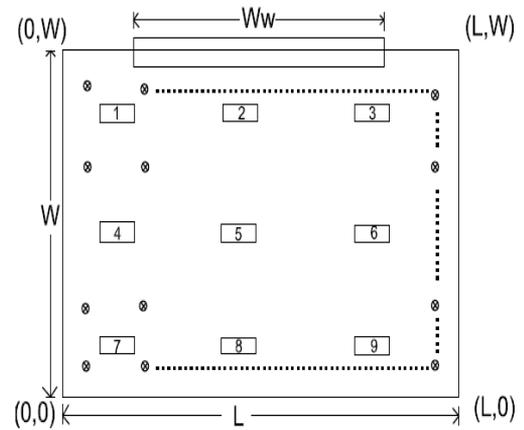
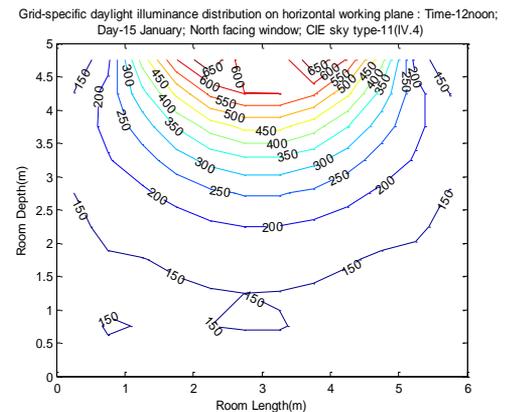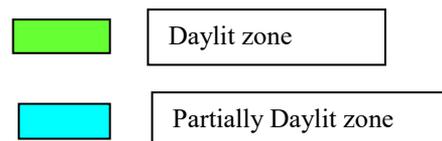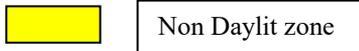

Figure 2. Layout of Luminaire and grid points

Figure 3. Daylight isolux diagram. winter (January), north facing window, 12 noon

For example, grid-specific daylight level distribution corresponding to **Figure 3** as obtained from Matlab simulation is given by.

Non Daylit zone (□ yellow box legend)

total_daylight =

```
111  183  420  597  696  560  560  694  594  416  180
108
151  219  333  462  562  601  600  560  460  331  218
149
165  214  274  354  422  463  463  422  352  273  213
164
162  196  228  274  316  340  340  315  273  228  195
163
150  175  191  216  241  254  254  240  216  191  173
148
142  158  165  178  191  200  200  190  177  163  157
139
132  147  149  155  162  166  165  160  153  145  142
127
132  145  143  145  148  150  149  146  141  137  136
124
139  152  149  148  150  151  151  147  144  140  140
128
138  144  141  139  141  142  141  139  135  132  133
127
```

Positions of 9 luminaires are shown in **Figure 2**. The top row luminaire (2) above the daylit zone can be put off (100% dimming) while two corner luminaires 1 and 3 need to provide significant contribution and thus set at 20% dimming level. In the same way, the luminaire (5) above partially daylit zone can be set at 80% dimming while luminaires 4 and 6 are set at 30% and 40% dimming level. The bottom row luminaires are also to be set at 20%, 20% and 0% dimming level as shown below- **Dim_Level=[20 100 20 30 80 40 20 20 0];**

With the set dimming level, the artificial light level distribution as obtained from Matlab simulation as.

Lamp_E =

```
267  293  254  211  174  158  157  172  208  247  279
253  315  349  309  257  219  202  205  225  259  304
331  298  313  356  324  274  239  221  221  240  270
309  331  303
312  360  331  290  258  244  242  255  279  311  333
306
315  366  342  303  279  267  267  273  292  319  339
313
322  377  356  323  305  295  298  305  317  338  352
320
324  384  364  336  319  314  317  321  329  348  362
329
327  389  373  346  335  333  335  336  342  363  376
340
325  387  372  347  337  340  343  340  343  364  378
341
286  343  330  312  303  305  313  309  308  320  326
295
```

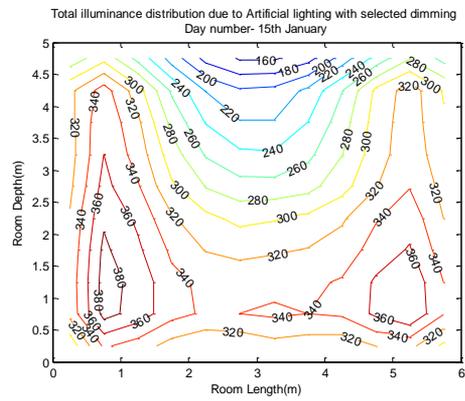The corresponding isolux diagram is shown in **Figure 4**.

Figure 4. Artificial light isolux diagram at set dimming value (January)

Accordingly the integrated light level distribution and average illuminance value, uniformity are achieved as:
total_E_integrated =

```
378  476  674  808  870  718  717  866  802  663  459
361  466  568  642  719  781  803  805  785  719  635
549  447
478  570  598  628  661  684  684  662  622  582  544
467  474  556  559  564  574  584  582  570  552  539
528  469  465  541  533  519  520  521  521  513  508
510  512  461  464  535  521  501  496  495  498  495
494  501  509  459
456  531  513  491  481  480  482  481  482  493  504
456
459  534  516  491  483  483  484  482  483  500  512
464
464  539  521  495  487  491  494  487  487  504  518
469
424  487  471  451  444  447  454  448  443  452  459
422
```

total_Eavg =538.61; total_Uo =0.67

The isolux diagram for the above integrated lighting is presented in **Figure 5**.
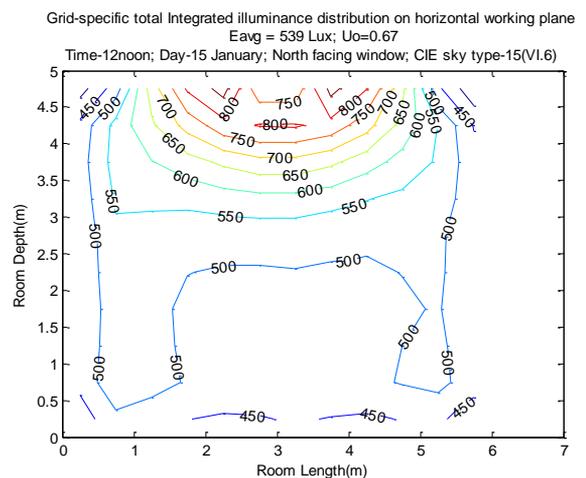

Figure 5. Integrated light isolux diagram: winter (January), north facing window, 12 noon

3. RESULTS AND ANALYSIS

Simulation is done for eight window orientations, five local times and three seasonal sky conditions with the identified

skies at Roorkee. The generated database is presented in the following part of this section only for north window orientation during winter season only. It shows specially reduction of lighting load compared to the artificial lighting installation without daylight integration.

Different Lighting design parameters during **winter** (J=15, sky type 15(VI.4)), for different times for north window orientation are presented in **Table 1** and in **Figure 6 (A-C).**

Table 1. Design parameters for $W_{nom} = 0^0$; winter**;** Full Lighting-Load = 648W

Local time	L-Load with dimming(W)	L_ Load reduction(W)	For daylight		For integrated light	
			E_{avg} (Lux)	U_o	E_{avg} (Lux)	U_o
8am	640.80	7.2	99	0.36	564.26	0.66
10am	496.8	151.2	209.66	0.39	607.91	0.66
12noon	410.4	237.6	231.7	0.39	556.34	0.64
2pm	396.0	252.0	272.33	0.38	566.55	0.65
4pm	547.2	100.8	126.56	0.36	568.28	0.71

The generated database for three seasonal conditions is analysed to address the following No.s with respect to window orientation-
i)   possible reduction of lighting load
ii)   best light quality i.e., overall uniformity on working plane
iii)   best light quantity i.e., average illuminance.

To address the first No., we consider the parameter. L_Load reduction (W). For each window orientation, L_Load reduction is added for three seasons and sum of total values are found out. Finally, these values are expressed as percentage of total L_Load with dimming as presented in **Table 2**.
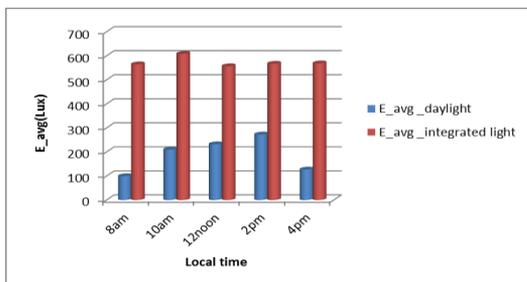

Figure 6. (A). Average illuminance (E_{avg}) on working plane
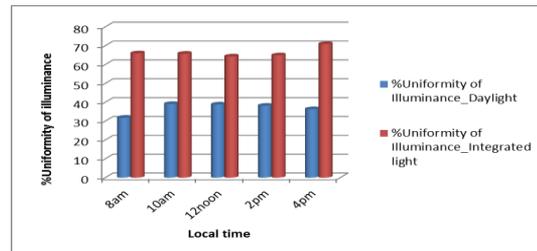W_{nom}= North; Season. Winter

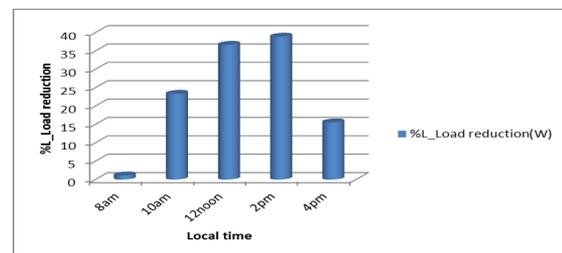**Figure 6. (B).** % Uniformity of illuminance on working plane W_{nom}= 0^0 (N). winter

Figure 6(C): % L-Load; W_{nom}= North; Season: Winter
Figure6 (A-C): Different Lighting design parameters during **winter** for W_{nom}= North

Table 2. Energy saving potential for different window orientations
(Total lighting load without dimming = 648*5*3 = 9720 W)

	Window orientations							
	N	NE	E	SE	S	SW	W	NW
Season	Summer							
Reduction of lighting load (W)	1137	993.6	1281.6	1224	1353.6	1231.2	1303.2	1274.4
Season	Equinox							
Reduction of lighting load (W)	813.6	981	1213.2	1396.8	1602	1360.8	1152	936
Season	Winter							
Reduction of lighting load (W)	748.8	865.8	1130.4	1393.2	1418.4	1432.8	1216.8	842.4
Total Load Reduction(W)	2699.4	2840.4	3625.2	4014	4374	4024.8	3672	3052.8
Load Reduction (%)	27.77	29.2	37.3	41.3	45	41.4	37.8	31.4

Maximum reduction of lighting load achieved for south facing window (45%); for South-East and South-West, this value > 40%. On the other hand, north facing window shows minimum reduction. Again, North-East and North-West also

show almost 30% of reduction. Thus, on an average 30% of light load can be reduced through daylight integration.
To address the second No., we compute the number of occurrences for the overall uniformity values ≥ 0.60%, ≥

0.55%, $\geq$ 0.50% and <0.50, since 0.60 is considered as desired value. This is shown in **Table 3**.

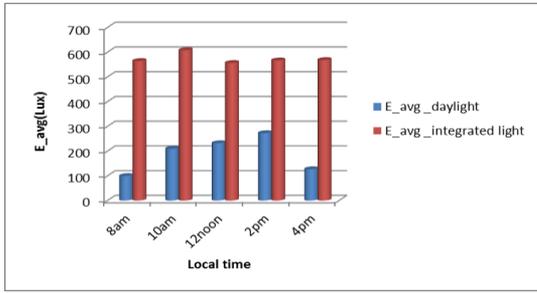**Figure 6. (A).** Average illuminance (E_{avg}) on working plane
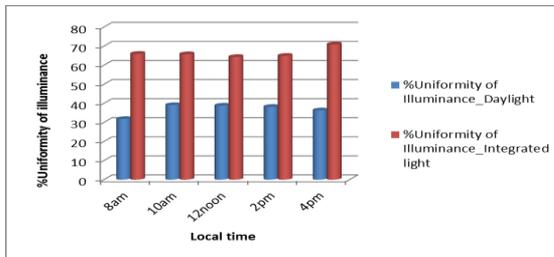W_{nom}= North; Season. Winter

Figure 6. (B). % Uniformity of illuminance on working plane W_{nom}= 0^0 (N). winter
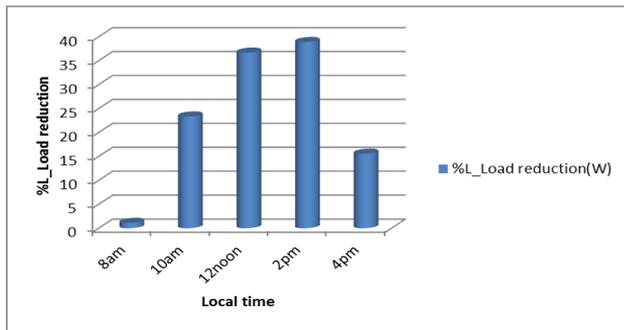

Figure 6(C): % L-Load; W_{nom}= North; Season: Winter
Figure6 (A-C): Different Lighting design parameters during **winter** for W_{nom}= North

Table 3. Number of occurrences. overall uniformity

Orientations	Uo$\geq$ 0.6	Uo$\geq$ 0.55	Uo$\geq$0.50	Uo<0.50
N	11	15	15	0
NE	10	11	11	4
E	6	9	10	5
SE	4	4	7	8
S	1	4	6	9
SW	4	6	7	7
W	8	8	9	6
NW	10	12	12	3

North facing window shows maximum number of occurrences (10) for Uo$\geq$ 0.60; moreover, the NE and NW facing windows also show the same result. On the other hand, S facing window show the minimum number of occurrence

(1); SE and SW facing window show relatively better result as 4.

Thus, N facing window provides best quality lighting on horizontal working plane.
The third No. can be addressed by the observation of the E_{avg} values for integrated light. It reveals that minimum desired value (500 Lux) is achieved in each simulation. It indicates desired quantity of light is ensured in the integrated lighting system.

Hence to ensure quality of light distribution, the energy saving opportunity is to be sacrificed by about 10%.
Energy saving potential of the daylight integrated lighting system is thoroughly studied in this paper through lighting simulation using the developed Matlab program. South facing window orientations viz., S, SE and SW show higher lighting saving of electrical energy whereas the north facing orientations, viz., N, NE and NW show better quality of integrated lighting on horizontal working plane.

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