ภาคผนวก ก

รายละเอียดประกอบการคำนวณด้วยวิธีลูเมนต์

ก1. รายละเอียดและตัวอย่างวิธีการคำนวณค่า CU

ในการคำนวณค่า CU มีวิธีการดังต่อไปนี้

ก1.1) แบ่งส่วนห้องเป็น 3 ส่วนดังแสดงในรูปที่ ก.1 เพื่อกำหนดค่าความสูงของส่วนเพดาน (Ceiling Cavity Height, HCC), ส่วนตัวห้อง (Room Cavity Height, HRC) และส่วนพื้น (Floor Cavity Height, HFC) จากนั้นนำค่าที่ได้ไปหาอัตราส่วนโพรงของแต่ละส่วน คือ อัตราส่วนโพรงเพดาน (Ceiling Cavity Ratio, CCR), อัตราส่วนโพรงห้อง (Room Cavity Ratio, RCR) และอัตราส่วนโพรงพื้น (Floor Cavity Ratio, FCR) ตามสมการที่ ก.1, ก.2 และ ก.3

$$CCR = [5HCC(W + L)] / (W \times L) \qquad (ก.1)$$

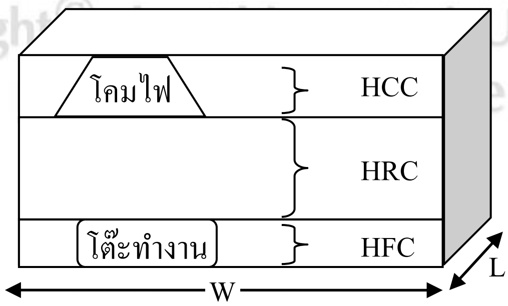
$$RCR = [5HRC(W + L)] / (W \times L) \qquad (ก.2)$$

$$FCR = [5HFC(W + L)] / (W \times L) \qquad (ก.3)$$

โดย

W ความกว้างของห้อง (m)

L ความยาวของห้อง (m)



รูปที่ ก.1 การแบ่งสัดส่วนห้อง

ตารางที่ ก.1 ค่าสัมประสิทธิ์การสะท้อนแสงของอาคาร

บริเวณ	เปอร์เซ็นต์การสะท้อนแสง	
	สำนักงาน, โรงเรียน, โรงงาน	ที่อยู่อาศัย
เพดาน	0.70-0.90	0.60-0.90
กำแพง (ผนัง)	0.40-0.60	0.35-0.60
อุปกรณ์ หรือ ตู้ โต๊ะ เก้าอี้	0.25-0.45	0.25-0.48
เครื่องใช้สำนักงาน	0.25-0.45	0.25-0.48
พื้นทั่วไป	0.20-0.45	0.15-0.35
พื้นโรงงาน	0.10-0.30	-

ก1.2) หาสัมประสิทธิ์การสะท้อนแสงของห้องเพดาน (Ceiling Reflectance, ρ_c) ของผนัง (Wall Reflectance, ρ_w) และของพื้น (Floor Reflectance, ρ_f) จากตารางที่ ก.1 [22]

ก1.3) จากนั้นนำค่า CCR, RCR, FCR, ρ_c, ρ_w และ ρ_f ไปเทียบในตารางที่ ก.2 เพื่อหาผลสัมฤทธิ์ซึ่งมีอยู่ 2 ส่วน คือ ประสิทธิผลการสะท้อนของโพรงเพดาน (Effective Ceiling Reflectance, ρ_{cc}) และประสิทธิผลการสะท้อนของโพรงพื้น (Effective Floor Reflectance, ρ_{fc})

ก1.4) สุดท้ายนำค่า RCR, ρ_w, ρ_{cc} และ ρ_{fc} ไปเทียบในตารางที่ ก.3 เพื่อหาค่า CU ตามชนิดของโคมที่ติดตั้ง

ตารางที่ ก.2 ตารางแสดงค่าประสิทธิผลการสะท้อน (Marc Schiler, 1992)

Per Cent Base† Reflectance	90									
Per Cent Wall Reflectance	90	80	70	60	50	40	30	20	10	0
Cavity Ratio										
0.2	89	88	88	87	86	85	85	84	84	82
0.4	88	87	86	85	84	83	81	80	79	76
0.6	87	86	84	82	80	79	77	76	74	73
0.8	87	85	82	80	77	75	73	71	69	67
1.0	86	83	80	77	75	72	69	66	64	62
1.2	85	82	78	75	72	69	66	63	60	57
1.4	85	80	77	73	69	65	62	59	57	52
1.6	84	79	75	71	67	63	59	56	53	50
1.8	83	78	73	69	64	60	56	53	50	48
2.0	83	77	72	67	62	56	53	50	47	43
2.2	82	76	70	65	59	54	50	47	44	40
2.4	82	75	69	64	58	53	48	45	41	37
2.6	81	74	67	62	56	51	46	42	38	35
2.8	81	73	66	60	54	49	44	40	36	34
3.0	80	72	64	58	52	47	42	38	34	30
3.2	79	71	63	56	50	45	40	36	32	28
3.4	79	70	62	54	48	43	38	34	30	27
3.6	78	69	61	53	47	42	36	32	28	25
3.8	78	69	60	51	45	40	35	31	27	23
4.0	77	69	58	51	44	39	33	29	25	22
4.2	77	62	57	50	43	37	32	28	24	21
4.4	76	61	56	49	42	36	31	27	23	20
4.6	76	60	55	47	40	35	30	26	22	19
4.8	75	59	54	46	39	34	28	25	21	18
5.0	75	59	53	45	38	33	28	24	20	16
6.0	73	61	49	41	34	29	24	20	16	11
7.0	70	58	45	38	30	27	21	18	14	08
8.0	68	55	42	35	27	23	18	15	12	06
9.0	66	52	38	31	25	21	16	14	11	05
10.0	65	51	36	29	22	19	15	11	09	04

Per Cent Base† Reflectance	80									
Per Cent Wall Reflectance	90	80	70	60	50	40	30	20	10	0
Cavity Ratio										
0.2	79	78	78	77	77	76	76	75	74	72
0.4	79	77	76	75	74	73	72	71	70	68
0.6	78	76	75	73	71	70	68	66	65	63
0.8	78	75	73	71	69	67	65	63	61	57
1.0	77	74	72	69	67	65	62	60	57	55
1.2	76	73	70	67	64	61	58	55	53	51
1.4	76	72	68	65	62	59	55	53	50	48
1.6	75	71	67	63	60	57	53	50	47	44
1.8	75	70	66	62	58	54	50	47	44	41
2.0	74	69	64	60	56	52	48	45	41	38
2.2	74	68	63	58	54	49	45	42	38	35
2.4	73	67	61	56	52	47	43	40	36	33
2.6	73	66	60	55	50	45	41	38	34	31
2.8	73	65	59	53	48	43	39	36	32	29
3.0	72	65	58	52	47	42	37	34	30	27
3.2	72	65	57	51	45	40	35	33	28	25
3.4	71	64	56	49	44	39	34	32	27	24
3.6	71	63	54	48	43	38	32	30	25	23
3.8	70	62	53	47	41	36	31	28	24	22
4.0	70	61	53	46	40	35	30	26	22	20
4.2	69	60	52	45	39	34	29	25	21	18
4.4	69	60	51	44	38	33	28	24	20	17
4.6	69	59	50	43	37	32	27	23	19	15
4.8	68	58	49	42	36	31	26	22	18	14
5.0	68	58	48	41	35	30	25	21	18	14
6.0	66	55	44	38	31	27	22	19	15	10
7.0	64	53	41	35	28	24	19	16	12	07
8.0	62	50	38	32	25	21	17	14	11	05
9.0	61	49	36	30	23	19	15	13	10	04
10.0	59	46	33	27	21	18	14	11	08	03

Per Cent Base† Reflectance	70									
Per Cent Wall Reflectance	90	80	70	60	50	40	30	20	10	0
Cavity Ratio										
0.2	70	69	68	68	67	67	66	66	65	64
0.4	69	68	67	66	65	64	63	62	61	58
0.6	69	67	65	64	63	61	59	58	57	54
0.8	68	66	64	62	60	58	56	55	53	50
1.0	68	65	62	60	58	55	53	52	50	47
1.2	67	64	61	59	57	54	50	48	46	44
1.4	67	63	60	58	55	51	47	45	44	41
1.6	67	62	59	56	53	47	45	43	41	38
1.8	66	61	58	54	51	46	42	40	38	35
2.0	66	60	56	52	49	45	40	38	36	33
2.2	66	60	55	51	48	43	38	36	34	32
2.4	65	60	54	50	46	41	37	35	32	30
2.6	65	59	54	49	45	40	35	33	30	28
2.8	65	59	53	48	43	38	33	30	28	26
3.0	64	58	52	47	42	37	32	29	27	24
3.2	64	58	51	46	40	36	31	28	25	23
3.4	64	57	50	45	39	35	29	27	24	22
3.6	63	56	49	44	38	33	28	25	22	20
3.8	63	56	49	43	37	32	27	24	21	19
4.0	63	55	48	42	36	31	26	23	20	17
4.2	62	55	47	41	35	30	25	22	19	16
4.4	62	54	46	40	34	29	24	21	18	15
4.6	62	53	45	39	33	28	24	21	17	14
4.8	62	53	45	38	32	27	23	20	16	13
5.0	61	52	44	36	31	26	22	19	16	12
6.0	60	51	41	35	28	24	19	16	13	09
7.0	58	48	38	32	26	22	17	14	11	06
8.0	57	46	35	29	23	19	15	13	10	05
9.0	56	45	33	27	21	18	14	12	09	04
10.0	55	43	31	25	19	16	12	10	08	03

Per Cent Base† Reflectance	60									
Per Cent Wall Reflectance	90	80	70	60	50	40	30	20	10	0
Cavity Ratio										
0.2	60	59	59	59	58	57	56	56	55	53
0.4	60	59	59	58	57	55	54	53	52	50
0.6	60	58	57	56	55	53	51	51	50	46
0.8	59	57	56	55	54	51	48	47	46	43
1.0	59	57	55	53	51	48	45	44	43	41
1.2	59	56	54	51	49	46	44	42	40	38
1.4	59	56	53	49	47	44	41	39	38	36
1.6	59	55	52	48	45	42	39	37	35	33
1.8	58	55	51	47	44	40	37	35	33	31
2.0	58	54	50	46	43	39	35	33	31	29
2.2	58	53	49	45	42	37	34	31	29	28
2.4	58	53	48	44	41	36	32	30	27	26
2.6	58	53	48	43	39	35	31	28	26	24
2.8	58	53	47	43	38	34	29	27	24	22
3.0	57	52	46	42	37	32	28	25	23	20
3.2	57	51	45	41	36	31	27	23	22	18
3.4	57	51	45	40	35	30	26	23	20	17
3.6	57	50	44	39	34	29	25	22	19	16
3.8	57	50	43	38	33	29	24	21	19	15
4.0	57	49	42	37	32	28	23	20	18	14
4.2	56	49	42	37	32	27	22	19	17	14
4.4	56	49	42	36	31	27	22	19	16	13
4.6	56	49	41	35	30	26	21	18	16	13
4.8	56	48	41	34	29	25	21	18	15	12
5.0	56	48	40	34	28	24	20	17	14	11
6.0	55	45	37	31	25	21	17	14	11	07
7.0	54	43	35	30	24	20	15	12	09	05
8.0	53	42	33	28	22	18	14	11	08	04
9.0	52	40	31	26	20	16	12	10	07	03
10.0	51	39	29	24	18	15	11	09	07	02

Per Cent Base† Reflectance	50									
Per Cent Wall Reflectance	90	80	70	60	50	40	30	20	10	0
Cavity Ratio										
0.2	50	50	49	49	48	48	47	46	46	44
0.4	50	49	48	48	47	46	45	45	44	42
0.6	50	48	47	46	45	44	43	42	41	38
0.8	50	48	47	45	44	42	40	39	38	36
1.0	50	48	46	44	43	41	38	37	36	34
1.2	50	47	45	43	41	39	36	35	34	29
1.4	50	47	45	42	40	38	35	34	32	27
1.6	50	47	44	41	39	36	33	32	30	26
1.8	50	46	43	40	38	35	31	30	28	25
2.0	50	46	43	40	37	34	30	28	26	24
2.2	50	46	42	38	36	33	29	27	24	22
2.4	50	46	42	37	35	31	27	25	23	21
2.6	50	46	41	37	34	30	26	23	21	20
2.8	50	46	41	36	33	29	25	22	20	19
3.0	50	45	40	36	32	28	24	21	19	17
3.2	50	44	39	35	31	27	23	20	18	16
3.4	50	44	39	35	30	26	22	19	17	15
3.6	50	44	39	34	29	25	21	18	16	14
3.8	50	44	38	34	29	25	21	17	15	13
4.0	50	44	38	33	28	24	20	17	15	12
4.2	50	43	37	32	28	24	20	17	14	12
4.4	50	43	37	32	27	23	19	16	13	11
4.6	50	43	36	31	26	22	18	15	13	10
4.8	50	43	36	31	26	22	18	15	12	09
5.0	50	42	35	30	25	21	17	14	12	09
6.0	50	42	34	29	23	19	15	13	10	06
7.0	49	41	32	27	21	18	14	11	08	05
8.0	49	40	30	25	19	16	12	10	07	03
9.0	48	39	29	24	18	15	11	09	07	03
10.0	47	37	27	22	17	14	10	08	06	02

* Values in this table are based on a length to width ratio of 1.6.

† Ceiling, floor or floor of cavity.

ตารางที่ ก.2 ตารางแสดงค่าประสิทธิผลการสะท้อน (Marc Schiler, 1992) (ต่อ)

Per Cent Base† Reflectance: 40

Per Cent Wall Reflectance / Cavity Ratio	90	80	70	60	50	40	30	20	10	0
0.2	40	40	39	39	39	38	38	37	36	36
0.4	41	40	39	39	38	37	36	35	34	34
0.6	41	40	39	38	37	36	34	33	32	31
0.8	41	40	38	37	36	35	33	32	31	29
1.0	42	40	38	37	35	33	32	31	29	27
1.2	42	40	38	36	34	32	30	29	27	25
1.4	42	39	37	35	33	31	29	27	25	23
1.6	42	39	37	35	32	30	27	25	23	22
1.8	42	39	36	34	31	29	26	24	22	21
2.0	42	39	36	34	31	28	25	23	21	19
2.2	42	39	36	33	30	27	24	22	19	18
2.4	43	39	35	33	29	27	24	21	18	17
2.6	43	39	35	32	29	26	23	20	17	15
2.8	43	39	35	32	28	25	22	19	16	14
3.0	43	39	35	31	27	24	21	18	16	13
3.2	43	39	35	31	27	23	20	71	15	13
3.4	43	39	34	30	26	23	20	17	14	12
3.6	44	39	34	30	26	22	19	16	14	11
3.8	44	38	33	29	25	22	18	16	13	10
4.0	44	38	33	29	25	21	18	15	12	10
4.2	44	38	33	29	24	21	17	15	12	10
4.4	44	38	33	28	24	20	17	14	11	09
4.6	44	38	32	28	23	19	16	14	11	08
4.8	44	38	32	27	22	19	16	13	10	08
5.0	45	38	31	27	22	19	15	13	10	07
6.0	44	37	30	25	20	17	13	11	08	05
7.0	44	36	29	24	19	16	12	10	07	04
8.0	44	35	28	23	18	15	11	09	06	03
9.0	44	35	26	21	16	13	10	08	05	02
10.0	43	34	25	20	15	12	08	07	05	02

Per Cent Base† Reflectance: 30

Per Cent Wall Reflectance / Cavity Ratio	90	80	70	60	50	40	30	20	10	0
0.2	31	31	30	30	29	29	29	28	28	27
0.4	31	31	30	30	29	28	28	27	26	25
0.6	32	31	30	29	28	27	26	26	25	23
0.8	32	31	30	29	28	26	25	25	23	22
1.0	33	32	30	29	27	25	24	23	22	20
1.2	33	32	30	28	27	25	23	22	21	19
1.4	34	32	30	28	26	24	22	21	19	18
1.6	34	33	29	27	25	23	22	20	18	17
1.8	35	33	29	27	25	23	21	19	17	16
2.0	35	33	29	26	24	22	20	18	16	14
2.2	36	32	29	26	24	22	19	17	15	13
2.4	36	32	29	26	24	22	19	16	14	12
2.6	36	32	29	25	23	21	18	16	14	12
2.8	37	33	29	25	23	21	17	15	13	11
3.0	37	33	29	25	22	20	17	15	12	10
3.2	37	33	29	25	22	19	16	14	12	10
3.4	37	33	29	25	22	19	16	14	11	09
3.6	38	33	29	24	21	18	15	13	10	09
3.8	38	33	28	24	21	18	15	13	10	08
4.0	38	33	28	24	21	18	14	12	09	07
4.2	38	33	28	24	20	17	14	12	09	07
4.4	39	33	28	24	20	17	14	11	09	06
4.6	39	33	28	24	20	17	13	10	08	06
4.8	39	33	28	24	20	17	13	10	08	05
5.0	39	33	28	24	19	16	13	10	08	05
6.0	39	33	27	23	18	15	11	09	06	04
7.0	40	33	26	22	17	14	10	08	05	03
8.0	40	33	26	21	16	13	09	07	04	02
9.0	40	33	25	20	15	12	09	07	04	02
10.0	40	32	24	19	14	11	08	06	03	01

Per Cent Base† Reflectance: 20

Per Cent Wall Reflectance / Cavity Ratio	90	80	70	60	50	40	30	20	10	0
0.2	21	20	20	20	20	20	19	19	19	17
0.4	22	21	20	20	20	19	19	18	18	16
0.6	23	21	21	20	19	19	18	18	17	15
0.8	24	22	21	20	19	19	18	17	16	14
1.0	25	23	22	20	19	18	17	16	15	13
1.2	25	23	22	20	19	17	17	16	14	12
1.4	26	24	22	20	18	17	16	15	13	12
1.6	26	24	22	20	18	17	16	15	13	11
1.8	27	25	23	20	18	17	15	14	12	10
2.0	28	25	23	20	18	16	15	13	11	09
2.2	28	25	23	20	18	16	14	12	10	09
2.4	29	26	23	20	18	16	14	12	10	08
2.6	29	26	23	20	18	16	14	11	09	08
2.8	30	27	23	20	18	15	13	11	09	07
3.0	30	27	23	20	17	15	13	11	09	07
3.2	31	27	23	20	17	15	12	11	09	06
3.4	31	27	23	20	17	15	12	10	08	06
3.6	32	27	23	20	17	15	12	10	08	05
3.8	32	28	23	20	17	15	12	10	07	05
4.0	33	28	23	20	17	14	11	09	07	05
4.2	33	28	23	20	17	14	11	09	07	04
4.4	34	28	24	20	17	14	11	09	07	04
4.6	34	29	24	20	17	14	11	09	07	04
4.8	35	29	24	20	17	13	10	08	06	04
5.0	35	29	24	20	16	13	10	08	06	04
6.0	36	30	24	20	16	13	10	08	05	02
7.0	36	30	24	20	15	12	09	07	04	02
8.0	37	30	23	19	15	12	08	06	03	01
9.0	37	29	23	19	14	11	08	06	03	01
10.0	37	29	22	18	13	10	07	05	03	01

Per Cent Base† Reflectance: 10

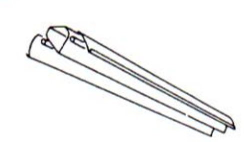
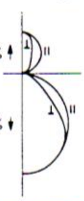
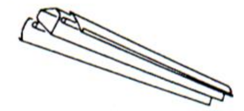
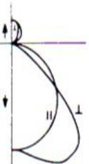
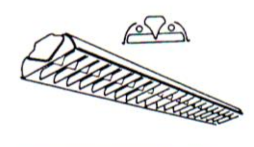
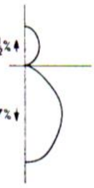
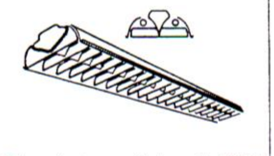
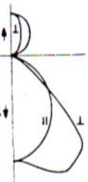
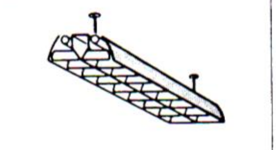
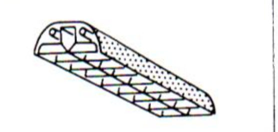
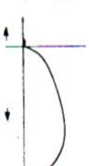
Per Cent Wall Reflectance / Cavity Ratio	90	80	70	60	50	40	30	20	10	0
0.2	11	11	11	10	10	10	10	09	09	09
0.4	12	11	11	11	11	10	10	09	09	08
0.6	13	13	12	11	11	10	10	09	08	08
0.8	15	14	13	12	11	10	10	09	08	07
1.0	16	14	13	12	12	11	10	09	08	07
1.2	17	15	14	13	12	11	10	09	07	06
1.4	18	16	14	13	12	11	10	09	07	06
1.6	19	17	15	14	12	11	09	08	07	06
1.8	19	17	15	14	13	11	09	08	06	05
2.0	20	18	16	14	13	11	09	08	06	05
2.2	21	19	16	14	13	11	09	07	06	05
2.4	22	19	17	15	13	11	09	07	06	05
2.6	23	20	17	15	13	11	09	07	06	04
2.8	23	20	18	16	13	11	09	07	05	03
3.0	24	21	18	16	13	11	09	07	05	03
3.2	25	21	18	16	13	11	09	07	05	03
3.4	26	22	18	16	13	11	09	07	05	03
3.6	26	22	19	16	13	11	09	06	04	03
3.8	27	23	19	17	14	11	09	06	04	02
4.0	27	23	20	17	14	11	09	06	04	02
4.2	28	24	20	17	14	11	09	06	04	02
4.4	28	24	20	17	14	11	08	06	04	02
4.6	29	25	20	17	14	11	08	06	04	02
4.8	29	25	20	17	14	11	08	06	04	02
5.0	30	25	20	17	14	11	08	06	04	02
6.0	31	26	21	18	14	11	08	06	03	01
7.0	32	27	21	17	13	11	08	06	03	01
8.0	33	27	21	17	13	10	07	05	03	01
9.0	34	28	21	17	13	10	07	05	02	01
10.0	34	28	21	17	12	10	07	05	02	01

Per Cent Base† Reflectance: 0

Per Cent Wall Reflectance / Cavity Ratio	90	80	70	60	50	40	30	20	10	0
0.2	02	02	02	01	01	01	01	00	00	0
0.4	04	03	03	02	02	02	01	01	00	0
0.6	05	05	04	03	03	02	02	01	01	0
0.8	07	06	05	04	04	03	02	02	01	0
1.0	08	07	06	05	04	03	02	02	01	0
1.2	10	08	07	06	05	04	03	02	01	0
1.4	11	09	08	07	06	04	03	02	01	0
1.6	12	10	09	07	06	05	03	02	01	0
1.8	13	11	09	08	07	05	04	03	01	0
2.0	14	12	10	09	07	05	04	03	01	0
2.2	15	13	11	09	07	06	04	03	01	0
2.4	16	13	11	09	08	06	04	03	01	0
2.6	17	14	12	10	08	06	05	03	02	0
2.8	17	15	13	10	08	07	05	03	02	0
3.0	18	16	13	11	09	07	05	03	02	0
3.2	19	16	14	11	09	07	05	03	02	0
3.4	20	17	14	12	09	07	05	03	02	0
3.6	20	17	15	12	10	08	05	04	02	0
3.8	21	18	15	12	10	08	05	04	02	0
4.0	22	18	15	13	10	08	05	04	02	0
4.2	22	19	16	13	10	08	06	04	02	0
4.4	23	19	16	13	10	08	06	04	02	0
4.6	23	20	17	13	11	08	06	04	02	0
4.8	24	20	17	14	11	08	06	04	02	0
5.0	25	21	17	14	11	08	06	04	02	0
6.0	27	23	18	15	12	09	06	04	02	0
7.0	28	24	19	15	12	09	06	04	02	0
8.0	30	25	20	15	12	09	06	04	02	0
9.0	31	25	20	15	12	09	06	04	02	0
10.0	31	25	20	15	12	09	06	04	02	0

* Values in this table are based on a length to width ratio of 1.6.
† Ceiling, floor or floor of cavity.

ตารางที่ ก.3 ตารางแสดงค่าสัมประสิทธิ์การใช้ประโยชน์ของดวงโคมชนิดต่างๆ (CU) โดยวิธี Zonal Cavity Method (Marc Schiler, 1992)

Typical Luminaire	Typical Intensity Distribution and Per Cent Lamp Lumens		ρ_{CC} →	80			70			50			30			10			0	WDRC
			ρ_W →	50	30	10	50	30	10	50	30	10	50	30	10	50	30	10	0	
	Maint. Cat.	SC	RCR ↓	Coefficients of Utilization for 20 Per Cent Effective Floor Cavity Reflectance (ρ_{FC} = 20)																
25	II	1.3	0	.99	.99	.99	.94	.94	.94	.85	.85	.85	.77	.77	.77	.69	.69	.69	.65	
			1	.87	.84	.81	.83	.80	.77	.75	.73	.71	.68	.66	.65	.62	.60	.59	.56	.236
			2	.77	.71	.67	.73	.68	.64	.67	.63	.60	.60	.58	.55	.55	.53	.51	.48	.220
	22½% ↑		3	.68	.62	.56	.65	.59	.54	.59	.55	.51	.54	.50	.47	.49	.46	.44	.41	.203
			4	.61	.54	.48	.58	.52	.47	.53	.48	.44	.48	.44	.41	.44	.41	.38	.35	.186
			5	.54	.47	.42	.52	.46	.41	.48	.42	.38	.44	.39	.36	.40	.36	.33	.31	.170
			6	.49	.42	.37	.47	.40	.36	.43	.38	.34	.40	.35	.32	.36	.33	.30	.27	.157
	65% ↓		7	.45	.37	.32	.43	.36	.32	.39	.34	.30	.36	.32	.28	.33	.29	.26	.24	.145
			8	.41	.34	.29	.39	.33	.28	.36	.31	.27	.33	.29	.25	.31	.27	.24	.22	.135
Porcelain-enameled reflector with			9	.37	.31	.26	.36	.30	.25	.33	.28	.24	.31	.26	.23	.28	.24	.22	.20	.126
35°CW shielding			10	.34	.28	.24	.33	.27	.23	.31	.25	.22	.28	.24	.21	.26	.22	.20	.18	.118
26	II	1.5/1.3	0	.95	.95	.95	.91	.91	.91	.83	.83	.83	.76	.76	.76	.69	.69	.69	.66	
			1	.85	.82	.79	.81	.79	.76	.75	.73	.71	.69	.67	.66	.63	.62	.61	.58	.197
	17% ↑		2	.75	.71	.67	.72	.68	.65	.67	.63	.61	.62	.59	.57	.57	.55	.53	.51	.194
			3	.67	.61	.57	.65	.59	.55	.60	.56	.52	.55	.52	.49	.51	.49	.46	.44	.184
			4	.60	.54	.49	.58	.52	.48	.54	.49	.45	.50	.46	.43	.46	.43	.41	.39	.173
			5	.54	.47	.43	.52	.46	.42	.49	.43	.40	.45	.41	.38	.42	.39	.36	.34	.162
	66% ↓		6	.49	.42	.37	.47	.41	.37	.44	.39	.35	.41	.37	.33	.38	.35	.32	.30	.151
			7	.44	.38	.33	.43	.37	.32	.40	.35	.31	.38	.33	.30	.35	.31	.28	.27	.141
			8	.40	.34	.29	.39	.33	.29	.37	.31	.28	.34	.30	.27	.32	.28	.26	.24	.132
Diffuse aluminum reflector with			9	.37	.31	.26	.36	.30	.26	.34	.29	.25	.32	.27	.24	.30	.26	.23	.21	.124
35°CW shielding			10	.34	.28	.24	.33	.27	.23	.31	.26	.23	.29	.25	.22	.28	.24	.21	.19	.117
27	II	1.0	0	.91	.91	.91	.86	.86	.86	.77	.77	.77	.68	.68	.68	.61	.61	.61	.57	
			1	.80	.77	.75	.76	.74	.71	.69	.67	.65	.62	.60	.59	.55	.54	.53	.50	.182
			2	.71	.67	.63	.68	.64	.60	.61	.58	.55	.55	.53	.51	.50	.48	.46	.43	.174
	23½% ↑		3	.63	.58	.53	.60	.55	.51	.55	.51	.47	.50	.46	.44	.45	.42	.40	.38	.163
			4	.57	.51	.46	.54	.49	.44	.49	.45	.41	.45	.41	.38	.41	.38	.35	.33	.151
			5	.51	.45	.40	.49	.43	.39	.45	.40	.36	.41	.37	.34	.37	.34	.31	.29	.140
			6	.46	.40	.35	.44	.38	.34	.41	.36	.32	.37	.33	.30	.34	.30	.28	.26	.130
	57% ↓		7	.42	.36	.31	.40	.35	.30	.37	.32	.29	.34	.30	.27	.31	.28	.25	.23	.121
			8	.38	.32	.28	.37	.31	.27	.34	.29	.26	.31	.27	.24	.29	.25	.23	.21	.113
Porcelain-enameled reflector with			9	.35	.29	.25	.34	.28	.25	.31	.27	.23	.29	.25	.22	.27	.23	.21	.19	.106
30°CW × 30°LW shielding			10	.33	.27	.23	.31	.26	.22	.29	.24	.21	.27	.23	.20	.25	.21	.19	.17	.099
28	II	1.5/1.1	0	.83	.83	.83	.79	.79	.79	.72	.72	.72	.65	.65	.65	.59	.59	.59	.56	
			1	.74	.72	.70	.71	.69	.67	.65	.63	.62	.59	.58	.57	.54	.53	.52	.50	.160
			2	.66	.62	.59	.64	.60	.57	.58	.56	.53	.54	.51	.49	.49	.47	.46	.44	.158
	17% ↑		3	.59	.54	.50	.57	.53	.49	.53	.49	.46	.48	.46	.43	.45	.42	.40	.38	.150
			4	.53	.48	.44	.51	.46	.42	.47	.43	.40	.44	.41	.38	.40	.38	.36	.34	.141
			5	.48	.42	.38	.46	.41	.37	.43	.39	.35	.40	.36	.33	.37	.34	.32	.30	.132
	56½% ↓		6	.44	.38	.34	.42	.37	.33	.39	.35	.31	.36	.33	.30	.34	.31	.28	.27	.124
			7	.40	.34	.30	.38	.33	.29	.36	.31	.28	.33	.30	.27	.31	.28	.25	.24	.116
			8	.36	.31	.27	.35	.30	.26	.33	.28	.25	.31	.27	.24	.29	.25	.23	.21	.109
Diffuse aluminum reflector with 35°CW			9	.33	.28	.24	.32	.27	.24	.30	.26	.23	.28	.24	.22	.26	.23	.21	.19	.102
× 35°LW shielding			10	.31	.25	.22	.30	.25	.22	.28	.24	.21	.26	.22	.20	.25	.21	.19	.18	.096
29	II	1.1	0	.75	.75	.75	.69	.69	.69	.57	.57	.57	.46	.46	.46	.37	.37	.37	.32	
			1	.66	.64	.62	.61	.59	.57	.51	.50	.48	.42	.41	.40	.33	.33	.32	.28	.094
			2	.59	.55	.52	.54	.51	.48	.46	.43	.41	.38	.36	.34	.30	.29	.28	.25	.091
	39% ↑		3	.52	.48	.44	.48	.44	.41	.41	.38	.35	.34	.32	.30	.27	.26	.25	.22	.085
			4	.47	.42	.38	.43	.39	.35	.37	.33	.31	.31	.28	.26	.25	.23	.22	.19	.079
			5	.42	.37	.33	.39	.34	.31	.33	.30	.27	.28	.25	.23	.23	.21	.20	.17	.073
			6	.38	.33	.29	.35	.31	.27	.30	.27	.24	.25	.23	.21	.21	.19	.18	.16	.068
	32% ↓		7	.35	.29	.26	.32	.28	.24	.28	.24	.21	.23	.21	.19	.19	.17	.16	.14	.063
			8	.32	.26	.23	.29	.25	.22	.25	.22	.19	.22	.19	.17	.18	.16	.15	.13	.059
Metal or dense diffusing sides with			9	.29	.24	.21	.27	.23	.20	.23	.20	.17	.20	.17	.15	.17	.15	.13	.12	.056
45°CW × 45°LW shielding			10	.27	.22	.19	.25	.21	.18	.22	.18	.16	.19	.16	.14	.16	.14	.12	.11	.052
30	IV	1.0	0	.61	.61	.61	.58	.58	.58	.55	.55	.55	.51	.51	.51	.48	.48	.48	.46	
			1	.54	.52	.50	.52	.50	.49	.49	.47	.46	.46	.45	.43	.43	.42	.41	.40	.159
	6% ↑		2	.48	.45	.42	.46	.44	.41	.44	.41	.39	.41	.39	.38	.39	.37	.36	.34	.145
			3	.43	.39	.36	.42	.38	.35	.39	.36	.34	.37	.35	.33	.35	.33	.31	.30	.132
			4	.39	.35	.32	.38	.34	.31	.36	.32	.30	.34	.31	.29	.32	.30	.28	.27	.121
			5	.35	.31	.28	.34	.30	.27	.32	.29	.27	.31	.28	.26	.29	.27	.25	.24	.111
	46% ↓		6	.32	.28	.25	.31	.27	.25	.30	.26	.24	.28	.25	.23	.27	.25	.23	.22	.102
			7	.29	.25	.22	.29	.25	.22	.27	.24	.22	.26	.23	.21	.25	.23	.21	.20	.095
			8	.27	.23	.20	.27	.23	.20	.25	.22	.20	.24	.21	.19	.23	.21	.19	.18	.088
Same as unit #29 except with top reflec-			9	.25	.21	.19	.25	.21	.18	.24	.20	.18	.23	.20	.18	.22	.19	.17	.16	.083
tors			10	.23	.20	.17	.23	.19	.17	.22	.19	.17	.21	.18	.16	.20	.18	.16	.15	.077

ตัวอย่างการคำนวณค่า CU

ของสำนักงานขนาด 8 x 8 x 4 เมตร มีโต๊ะสูง 1 เมตร หลอดไฟสูงจากพื้น 3.5 เมตร ที่ต้องการติดตั้งโคมหลอดฟลูออเรสเซนต์ขนาด 36 วัตต์ 2 หลอดต่อโคม โดยโคมเป็นชนิดแบบบานเกล็ด (หลอดไฟมีฟลักซ์ส่องสว่างเฉลี่ย 2,970 lm ฟลักซ์ส่องสว่างเริ่มต้น 3,300 lm)

วิธีทำ จากขนาดห้อง ระยะการติดตั้งหลอดไฟ และความสูงโต๊ะจะได้ค่า W = 8, L = 8, HCC = 0.5, HRC = 2.5 และ HFC = 1 ซึ่งสามารถคำนวณอัตราส่วนโพรงจากสมการที่ ก.1, ก.2 และ ก.3

$$CCR = [5\times 0.5(8+8)]/(8\times 8) = 0.625 \approx 0.6$$

$$RCR = [5\times 2.5(8+8)]/(8\times 8) = 3.125 \approx 3.0$$

$$FCR = [5\times 1.0(8+8)]/(8\times 8) = 1.250 \approx 1.2$$

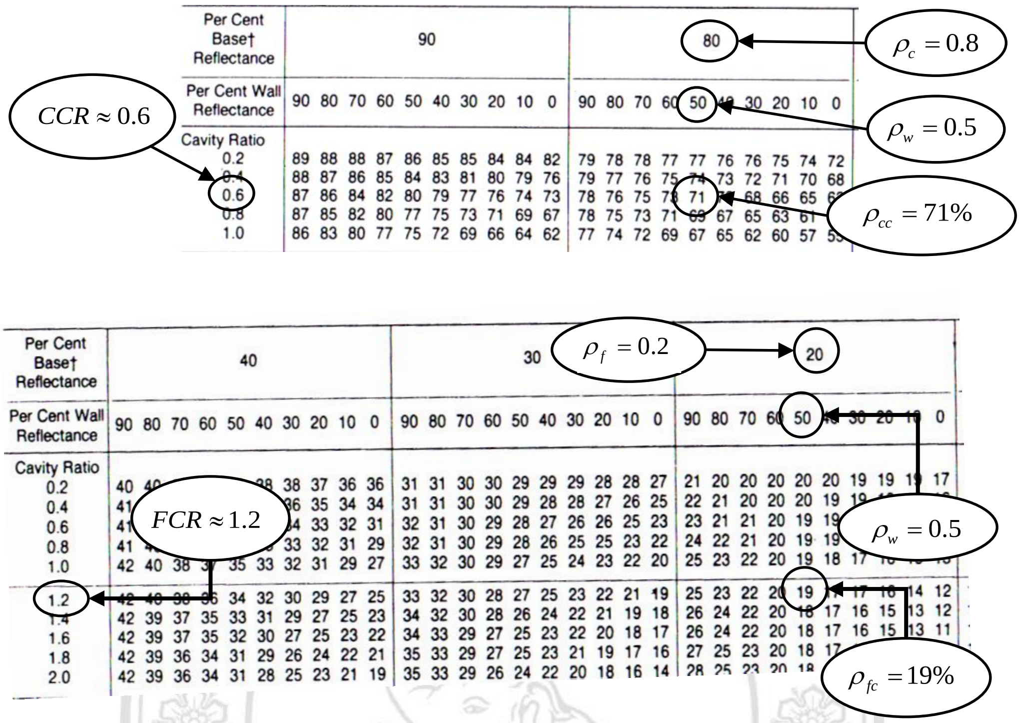
จากตารางที่ ก.1 ได้ค่า $\rho_c = 0.8$, $\rho_w = 0.5$ และ $\rho_f = 0.2$ จากนั้นนำค่าที่ได้ไปเทียบในตารางที่ ก.2 จะได้ค่า ρ_{cc} และ ρ_{fc} ดังแสดงในรูปที่ ก.2

จากค่า $\rho_c = 0.8$, $\rho_w = 0.5$ และ $CCR \approx 0.6$ ได้ค่า $\rho_{cc} = 71\% \approx 0.70$

จากค่า $\rho_f = 0.2$, $\rho_w = 0.5$ และ $FCR \approx 1.2$ ได้ค่า $\rho_{fc} = 19\% = 0.19$

นำค่า RCR, ρ_w , ρ_{cc} และ ρ_{fc} ที่ได้ไปเทียบกับชนิดโคม ซึ่งเป็นชนิดที่ 28 ในตารางที่ ก.3 จะได้ค่า CU ดังแสดงในรูปที่ ก.3

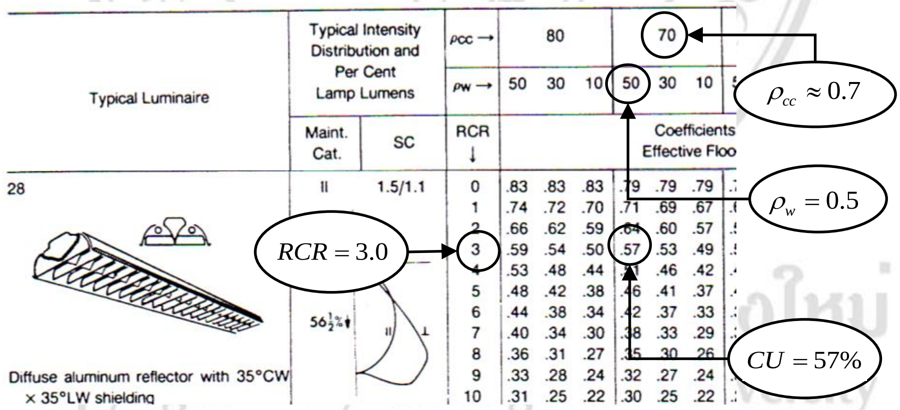
จากค่า $RCR = 3.0$, $\rho_w = 0.5$ และ $\rho_{cc} \approx 0.7$ ได้ค่า $CU = 57\% \approx 0.57$



Per Cent Base† Reflectance	90										80									
Per Cent Wall Reflectance	90	80	70	60	50	40	30	20	10	0	90	80	70	60	50	[illegible]	30	20	10	0
Cavity Ratio																				
0.2	89	88	88	87	86	85	85	84	84	82	79	78	78	77	77	76	76	75	74	72
0.4	88	87	86	85	84	83	81	80	79	76	79	77	76	75	74	73	72	71	70	68
0.6	87	86	84	82	80	79	77	76	74	73	78	76	75	[illegible]	71	[illegible]	68	66	65	[illegible]
0.8	87	85	82	80	77	75	73	71	69	67	78	75	73	71	69	67	65	63	61	[illegible]
1.0	86	83	80	77	75	72	69	66	64	62	77	74	72	69	67	65	62	60	57	[illegible]

Per Cent Base† Reflectance	40										30										20									
Per Cent Wall Reflectance	90	80	70	60	50	40	30	20	10	0	90	80	70	60	50	40	30	20	10	0	90	80	70	60	50	[illegible]	[illegible]	[illegible]	[illegible]	0
Cavity Ratio																														
0.2	40	40	[illegible]	[illegible]	[illegible]	38	38	37	36	36	31	31	30	30	29	29	29	28	28	27	21	20	20	20	20	20	19	19	19	17
0.4	41	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	36	35	34	34	31	31	30	30	29	28	28	27	26	25	22	21	20	20	20	19	19	[illegible]	[illegible]	[illegible]
0.6	41	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	34	33	32	31	32	31	30	29	28	27	26	26	25	23	23	21	21	20	19	19	[illegible]	[illegible]	[illegible]	[illegible]
0.8	41	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	33	32	31	29	32	31	30	29	28	26	25	25	23	22	24	22	21	20	19	19	[illegible]	[illegible]	[illegible]	[illegible]
1.0	42	40	38	[illegible]	35	33	32	31	29	27	33	32	30	29	27	25	24	23	22	20	25	23	22	20	19	18	17	[illegible]	[illegible]	[illegible]
1.2	42	40	38	36	34	32	30	29	27	25	33	32	30	28	27	25	23	22	21	19	25	23	22	20	19	[illegible]	[illegible]	[illegible]	14	12
1.4	42	39	37	35	33	31	29	27	25	23	34	32	30	28	26	24	22	21	19	18	26	24	22	20	18	17	16	15	13	12
1.6	42	39	37	35	32	30	27	25	23	22	34	33	29	27	25	23	22	20	18	17	26	24	22	20	18	17	16	15	13	11
1.8	42	39	36	34	31	29	26	24	22	21	35	33	29	27	25	23	21	19	17	16	27	25	23	20	18	17	[illegible]	[illegible]	[illegible]	[illegible]
2.0	42	39	36	34	31	28	25	23	21	19	35	33	29	26	24	22	20	18	16	14	28	25	23	20	18	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]

รูปที่ ก.2 การหาค่า ρ_{cc} และ ρ_{fc}



Typical Luminaire	Typical Intensity Distribution and Per Cent Lamp Lumens		ρ_{cc} →	80			70		
			ρ_w →	50	30	10	50	30	10
	Maint. Cat.	SC	RCR ↓				Coefficients	Effective Floo	
28	II	1.5/1.1	0	.83	.83	.83	.79	.79	.79
			1	.74	.72	.70	.71	.69	.67
			2	.66	.62	.59	[illegible]	.60	.57
			3	.59	.54	.50	.57	.53	.49
			4	.53	.48	.44	[illegible]	.46	.42
			5	.48	.42	.38	.46	.41	.37
			6	.44	.38	.34	.42	.37	.33
			7	.40	.34	.30	.38	.33	.29
			8	.36	.31	.27	.35	.30	.26
Diffuse aluminum reflector with 35°CW × 35°LW shielding			9	.33	.28	.24	.32	.27	.24
			10	.31	.25	.22	.30	.25	.22

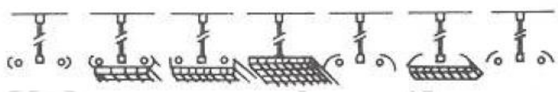
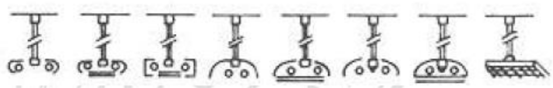
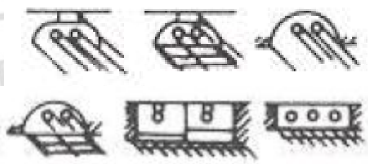
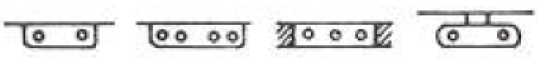
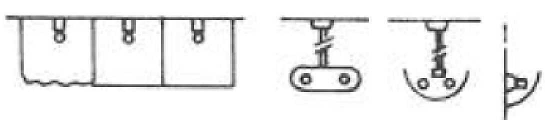
รูปที่ ก.3 การหาค่า CU

ก2. รายละเอียดและตัวอย่างวิธีการคำนวณค่า LDD

ในการคำนวณค่า LDD มีวิธีการคำนวณ ดังนี้

ก2.1) กำหนดประเภทของโคมตามตารางที่ ก.4

ตารางที่ ก.4 รายละเอียดประเภทของโคมแต่ละชนิด (ชาญศักดิ์ อภัยนิพัฒน์, 2550)

ประเภทโคม	รายละเอียด	รูปลักษณะโคม
1	เป็นดวงโคมแบบกึ่งกระจายแสงลง ดวงโคมเป็นแบบเปิด	
2	ด้านบนเป็นแบบเปิด เช่นเดียวกับประเภทที่ 1 แต่มีตะแกรงอยู่ด้านล่าง	
3	คล้ายกับประเภทที่ 2 แต่ตะแกรงมีความถี่มากกว่า คือ ระยะระหว่างตะแกรงน้อยกว่า 1 นิ้ว	
4	เป็นแบบกระจายแสงลง ด้านบนปิดและอาจมีตะแกรงอยู่ด้านล่าง	
5	เป็นแบบกระจายแสงลง หรือกึ่งกระจายแสงลง ตัวดวงโคมปิดมิดชิด	
6	เป็นแบบกระจายแสงลง หรือกึ่งกระจายแสงลง ใช้ส่องสว่างเพดานหรือแนวเพดานเป็นส่วนใหญ่	

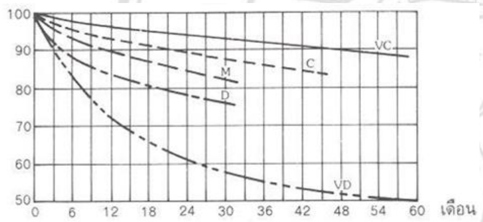
ก2.2) กำหนดสภาพความสะอาดของห้อง

VC	หมายถึง	สภาพห้องที่มีความสะอาดมาก (Very Clean)
C	หมายถึง	สภาพห้องที่มีความสะอาด (Clean)
M	หมายถึง	สภาพห้องที่มีความสะอาดปานกลาง (Medium)
D	หมายถึง	สภาพห้องที่มีความสกปรก (Dirty)
VD	หมายถึง	สภาพห้องที่มีความสกปรกมาก (Very Durty)

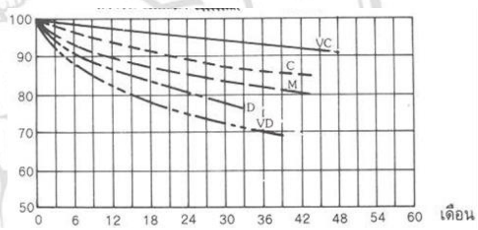
ก2.3) กำหนดระยะเวลาในการทำความสะอาดของห้อง (เดือน/ครั้ง)

โดยเลือกจาก 0, 3, 6, 9, 12, 15, 18, 21 หรือ 24 เดือน/ครั้ง

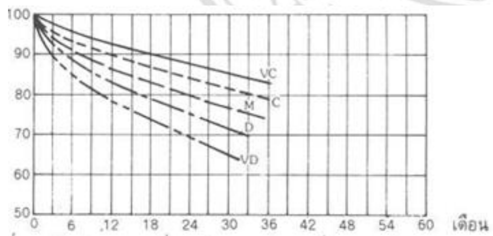
ก2.4) จากนั้นนำไปเทียบเพื่อหาค่า LDD จากกราฟในรูปที่ ก.4



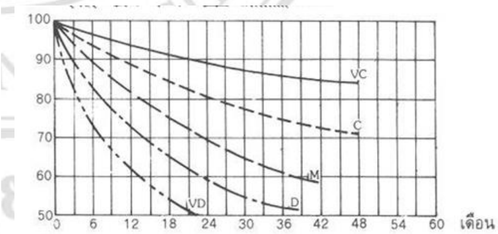
ประเภทที่ 1



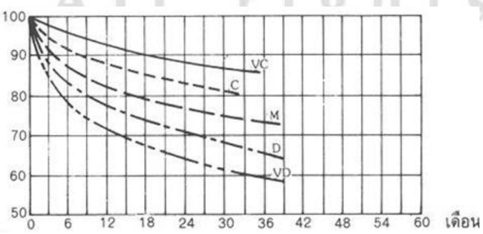
ประเภทที่ 2



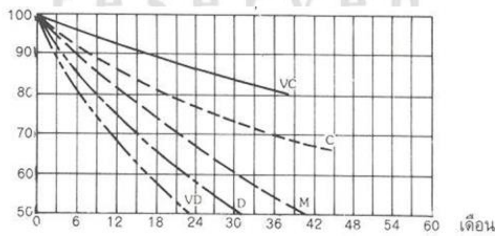
ประเภทที่ 3



ประเภทที่ 4



ประเภทที่ 5



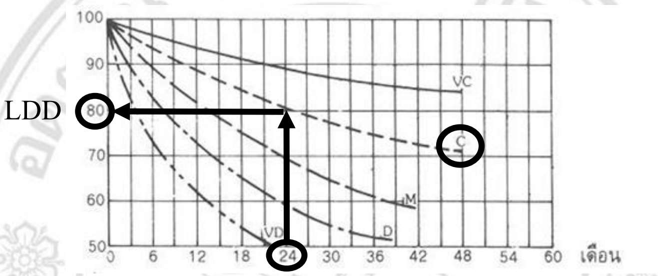
ประเภทที่ 6

รูปที่ ก.4 กราฟค่าความเสื่อมจากความสกปรกของดวงโคม (Marc Schiler, 1992)

ตัวอย่างการคำนวณค่า LDD

โคมหลอดฟลูออเรสเซนต์ขนาด 36 วัตต์ 2 หลอดต่อโคม โดยโคมเป็นชนิดแบบมีตะแกรง สภาพห้องสะอาด และมีระยะเวลาการทำความสะอาด 24 เดือน/ครั้ง มีวิธีคำนวณดังนี้

วิธีทำ เลือกประเภทของโคมจากตาราง ก.4 จะได้ประเภทของโคมเป็นโคมประเภทที่ 4 โดยสภาพห้องที่มีความสะอาด (Clean) เลือกใช้เส้นกราฟ C และ ระยะเวลาการทำความสะอาด 12 เดือน/ครั้ง จากนั้นนำค่าทั้งหมดมาลากเส้นจากระยะเวลาการทำความสะอาดตัดเส้นกราฟ C ดังแสดงในรูปที่ ก.5 จะได้ค่า LDD = 0.8



รูปที่ ก.5 ค่า LDD ของโคมประเภทที่ 4

ก3. ตัวอย่างวิธีการออกแบบระบบไฟฟ้าแสงสว่าง

ทำการติดตั้งหลอดฟลูออเรสเซนต์ 36 Watt (ปริมาณความสว่างประมาณ 2,500-2,700 lm โดยมีค่าแสงสว่างเริ่มต้น 3700 lm) 2 หลอดต่อโคม โดยโคมมีค่าสัมประสิทธิการสะท้อน 80% ในห้องกว้าง 8 x 8 เมตร ต้องการแสงสว่าง 300 lux มีการคำนวณดังนี้

วิธีทำ ค่าความส่องสว่างของการใช้งาน = 300 lux, LDD = 0.8 และ CU 0.8

หาค่า LDD จากสมการที่ 2.3 จะได้

$$LDD = 2,500 / 3,700 = 0.676$$

หาค่า TL จากการแทนค่าทั้งหมดในสมการที่ 2.4

$$TL = 300 \times (8 \times 8) / (0.8 \times 0.676 \times 0.8) = 44,776 lm$$

ดังนั้น จะได้ค่าฟลักซ์ส่องสว่างรวมของบริเวณนั้น 44,776 lm หาค่าจำนวนโคม (N) ที่ต้องติดตั้งจากสมการที่ 2.5

$$N = 44,776 / (2,500 \times 2) = 8.9$$

เพราะฉะนั้นห้องนี้ควรติดตั้งโคมจำนวน 9 โคม

ภาคผนวก ข

รายละเอียดของอุปกรณ์

ข1. รายละเอียดข้อมูลของหลอดฟลูออเรสเซนต์

TL-D Standard Colours

TL-D 36W/54-765 1SL

TL-D Standard Colors lamps (tube diameter of 26 mm) create atmospheres from warm white to cool daylight. Lamps with moderate efficacy and color rendering.

• General Characteristics

Cap-Base	G13 [Medium Bi-Pin Fluorescent]
Bulb	T8 [26 mm]
Life to 10% failures EM	10000 hr
Life to 50% failures EM	13000 hr

• Light Technical Characteristics

Color Code	54-765
Color Rendering Index	72 Ra8
Color Designation (text)	Cool Daylight
Color Temperature	6200 K
Luminous Flux Lamp EM	2500 Lm
Lumen Maintenance 2000h	90 %
Lumen Maintenance 5000h	80 %
Lumen Maintenance 10000h	75 %
Lumen Maintenance 15000h	70 %
Luminance Average EM	0.95 cd/cm2
Chromaticity Coordinate X	315 -
Chromaticity Coordinate Y	341 -

• Electrical Characteristics

Lamp Wattage	36 W
Lamp Wattage EM	36.0 W
Lamp Voltage	103 V
Lamp Current EM	0.440 A
Dimmable	Yes

• Environmental Characteristics

Energy Efficiency Label (EEL)	B
Mercury (Hg) Content	8.0 mg

• Product Dimensions

Base Face to Base Face A	1199.4 (max) mm
Insertion Length B	1204.1 (min), 1206.5 (max) mm
Overall Length C	1213.6 (max) mm
Diameter D	28 (max) mm

• Product Data

Order code	928048505453
Full product code	928048505453
Full product name	TL-D 36W/54-765 1SL
Order product name	TL-D 36W/54-765 1SL/25
Pieces per pack	1
Packing configuration	25
Packs per outerbox	25
Bar code on pack - EAN1	6923410770322
Bar code on outerbox - EAN3	6923410770339
Logistic code(s) - 12NC	928048505453
ILCOS code	FD-36/62/2A-E-G13
Net weight per piece	0.140 kg

Warnings and Safety

• A lamp breaking is extremely unlikely to have any impact on your health. If a lamp breaks, ventilate the room for 30 minutes and remove the parts, preferably with gloves. Put them in a sealed plastic bag and take it to your local waste facilities for recycling. Do not use a vacuum cleaner.

ข2. รายละเอียดข้อมูลของหลอด LED

รายละเอียดสินค้า

Long Lifespan(50,000Hrs)
Notable Energy-saving(70%~80%)
Convenient installation
Healthy Ray, No UV or IR radiation
High CRI(>75%)
Total Harmonic Distortion (THD): < 15%
Extensive Ranges of Applications
APPROVAL MARKS: CE, RoHS

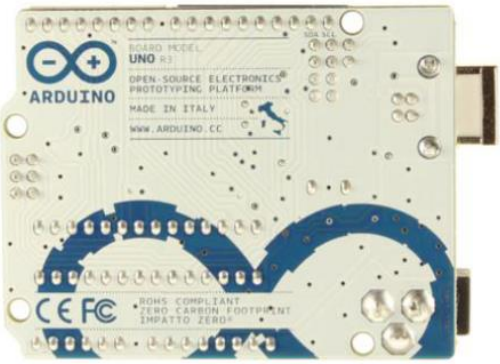
Specification:

Item No		PET-T82-10W	PET-T84-18W
Wattage		10W	18W
Dimension(D×L)		Φ26×605mm	Φ26×1215mm
Material		Aluminum +pc cover	
Input Voltage		DC 12/24V	
Power Efficiency		> 92%	
Luminous Flux		900LM	1620 LM
LED Color	Warm White	2800-3000K	
	Nature White	4000-4500K	
	Day White	5500-6300K	
	Cool White	6300-7000K	
CRI		> 75	
Light angle		156Degree	164Degree
Life span		50000Hrs	
Working Temperature		-20~40 ℃	
Environment Humidity		0%-95%	
Rotatable Cap		Fittings Selection	
Certification		CE, ROHS	

ข3. รายละเอียดข้อมูลของไมโครคอนโทรเลอร์ Arduino Atmega 328 รุ่น UNO R3

Arduino Uno

Arduino Uno R3 Front



Arduino Uno R3 Back

Overview

The Arduino Uno is a microcontroller board based on the ATmega328 (datasheet). It has 14 digital input/output pins (of which 6 can be used as PWM outputs), 6 analog inputs, a 16 MHz crystal oscillator, a USB connection, a power jack, an ICSP header, and a reset button. It contains everything needed to support the microcontroller; simply connect it to a computer with a USB cable or power it with a AC-to-DC adapter or battery to get started.

The Uno differs from all preceding boards in that it does not use the FTDI USB-to-serial driver chip. Instead, it features the Atmega16U2 (Atmega8U2 up to version R2) programmed as a USB-to-serial converter.
Revision 2 of the Uno board has a resistor pulling the 8U2 HWB line to ground, making it easier to put into DFU mode.
Revision 3 of the board has the following new features:

- 1.0 pinout: added SDA and SCL pins that are near to the AREF pin and two other new pins placed near to the RESET pin, the IOREF that allow the shields to adapt to the voltage provided from the board. In future, shields will be compatible both with the board that use the AVR, which operate with 5V and with the Arduino Due that operate with 3.3V. The second one is a not connected pin, that is reserved for future purposes.
- Stronger RESET circuit.
- Atmega 16U2 replace the 8U2.

"Uno" means one in Italian and is named to mark the upcoming release of Arduino 1.0. The Uno and version 1.0 will be the reference versions of Arduino, moving forward. The Uno is the latest in a series of USB Arduino boards, and the reference model for the Arduino platform; for a comparison with previous versions, see the index of Arduino boards.

Summary

Microcontroller	ATmega328
Operating Voltage	5V
Input Voltage (recommended)	7-12V
Input Voltage (limits)	6-20V
Digital I/O Pins	14 (of which 6 provide PWM output)
Analog Input Pins	6
DC Current per I/O Pin	40 mA
DC Current for 3.3V Pin	50 mA
Flash Memory	32 KB (ATmega328) of which 0.5 KB used by bootloader
SRAM	2 KB (ATmega328)
EEPROM	1 KB (ATmega328)
Clock Speed	16 MHz

Memory

The ATmega328 has 32 KB (with 0.5 KB used for the bootloader). It also has 2 KB of SRAM and 1 KB of EEPROM (which can be read and written with the EEPROM library).

Input and Output

Each of the 14 digital pins on the Uno can be used as an input or output, using pinMode(), digitalWrite(), and digitalRead() functions. They operate at 5 volts. Each pin can provide or receive a maximum of 40 mA and has an internal pull-up resistor (disconnected by default) of 20-50 kOhms. In addition, some pins have specialized functions:

- **Serial: 0 (RX) and 1 (TX).** Used to receive (RX) and transmit (TX) TTL serial data. These pins are connected to the corresponding pins of the ATmega8U2 USB-to-TTL Serial chip.
- **External Interrupts: 2 and 3.** These pins can be configured to trigger an interrupt on a low value, a rising or falling edge, or a change in value. See the attachInterrupt() function for details.
- **PWM: 3, 5, 6, 9, 10, and 11.** Provide 8-bit PWM output with the analogWrite() function.
- **SPI: 10 (SS), 11 (MOSI), 12 (MISO), 13 (SCK).** These pins support SPI communication using the SPI library.
- **LED: 13.** There is a built-in LED connected to digital pin 13. When the pin is HIGH value, the LED is on, when the pin is LOW, it's off.

The Uno has 6 analog inputs, labeled A0 through A5, each of which provide 10 bits of resolution (i.e. 1024 different values). By default they measure from ground to 5 volts, though is it possible to change the upper end of their range using the AREF pin and the analogReference() function. Additionally, some pins have specialized functionality:

- **TWI: A4 or SDA pin and A5 or SCL pin.** Support TWI communication using the Wire library.

There are a couple of other pins on the board:

- **AREF.** Reference voltage for the analog inputs. Used with analogReference().
- **Reset.** Bring this line LOW to reset the microcontroller. Typically used to add a reset button to shields which block the one on the board.

See also the mapping between Arduino pins and ATmega328 ports. The mapping for the Atmega8, 168, and 328 is identical.

Communication

The Arduino Uno has a number of facilities for communicating with a computer, another Arduino, or other microcontrollers. The ATmega328 provides UART TTL (5V) serial communication, which is available on digital pins 0 (RX) and 1 (TX). An ATmega16U2 on the board channels this serial communication over USB and appears as a virtual com port to software on the computer. The '16U2 firmware uses the standard USB COM drivers, and no external driver is needed. However, on Windows, a .inf file is required. The Arduino software includes a serial monitor which allows simple textual data to be sent to and from the Arduino board. The RX and TX LEDs on the board will flash when data is being transmitted via the USB-to-serial chip and USB connection to the computer (but not for serial communication on pins 0 and 1).

A SoftwareSerial library allows for serial communication on any of the Uno's digital pins.

The ATmega328 also supports I2C (TWI) and SPI communication. The Arduino software includes a Wire library to simplify use of the I2C bus: see the documentation for details. For SPI communication, use the SPI library.

Programming

The Arduino Uno can be programmed with the Arduino software (download). Select "Arduino Uno from the **Tools > Board** menu (according to the microcontroller on your board). For details, see the reference and tutorials.

The ATmega328 on the Arduino Uno comes preburned with a bootloader that allows you to upload new code to it without the use of an external hardware programmer. It communicates using the original STK500 protocol (reference, C header files).

You can also bypass the bootloader and program the microcontroller through the ICSP (In-Circuit Serial Programming) header; see these instructions for details.

The ATmega16U2 (or 8U2 in the rev1 and rev2 boards) firmware source code is available . The ATmega16U2/8U2 is loaded with a DFU bootloader, which can be activated by:

- On Rev1 boards: connecting the solder jumper on the back of the board (near the map of Italy) and then resetting the 8U2.
- On Rev2 or later boards: there is a resistor that pulling the 8U2/16U2 HWB line to ground, making it easier to put into DFU mode.

You can then use Atmel's FLIP software (Windows) or the DFU programmer (Mac OS X and Linux) to load a new firmware. Or you can use the ISP header with an external programmer (overwriting the DFU bootloader). See this user-contributed tutorial for more information.

Automatic (Software) Reset

Rather than requiring a physical press of the reset button before an upload, the Arduino Uno is designed in a way that allows it to be reset by software running on a connected computer. One of the hardware flow control lines (DTR) of the ATmega8U2/16U2 is connected to the reset line of the ATmega328 via a 100 nanofarad capacitor. When this line is asserted (taken low), the reset line drops long enough to reset the chip. The Arduino software uses this capability to allow you to upload code by simply pressing the upload button in the Arduino environment. This means that the bootloader can have a shorter timeout, as the lowering of DTR can be well-coordinated with the start of the upload.

This setup has other implications. When the Uno is connected to either a computer running Mac OS X or Linux, it resets each time a connection is made to it from software (via USB). For the following half-second or so, the bootloader is running on the Uno. While it is programmed to ignore malformed data (i.e. anything besides an upload of new code), it will intercept the first few bytes of data sent to the board after a connection is opened. If a sketch running on the board receives one-time configuration or other data when it first starts, make sure that the software with which it communicates waits a second after opening the connection and before sending this data.

The Uno contains a trace that can be cut to disable the auto-reset. The pads on either side of the trace can be soldered together to re-enable it. It's labeled "RESET-EN". You may also be able to disable the auto-reset by connecting a 110 ohm resistor from 5V to the reset line; see this forum thread for details.

USB Overcurrent Protection

The Arduino Uno has a resettable polyfuse that protects your computer's USB ports from shorts and overcurrent. Although most computers provide their own internal protection, the fuse provides an extra layer of protection. If more than 500 mA is applied to the USB port, the fuse will automatically break the connection until the short or overload is removed.

Physical Characteristics

The maximum length and width of the Uno PCB are 2.7 and 2.1 inches respectively, with the USB connector and power jack extending beyond the former dimension. Four screw holes allow the board to be attached to a surface or case. Note that the distance between digital pins 7 and 8 is 160 mil (0.16"), not an even multiple of the 100 mil spacing of the other pins.

ข4. รายละเอียดข้อมูลของบอร์ดคอมพิวเตอร์ขนาดเล็ก (Raspberry Pi 2 Model B)

Raspberry Pi

Raspberry Pi 2, Model B

Product Name	**Raspberry Pi 2, Model B**
Product Description	The Raspberry Pi 2 delivers 6 times the processing capacity of previous models. This second generation Raspberry Pi has an upgraded Broadcom BCM2836 processor, which is a powerful ARM Cortex-A7 based quad-core processor that runs at 900MHz. The board also features an increase in memory capacity to 1Gbyte.
RS Part Number	**832-6274**

Specifications

Chip	Broadcom BCM2836 SoC
Core architecture	Quad-core ARM Cortex-A7
CPU	900 MHz
GPU	Dual Core VideoCore IV® Multimedia Co-Processor
	Provides Open GL ES 2.0, hardware-accelerated OpenVG, and 1080p30 H.264 high-profile decode
	Capable of 1Gpixel/s, 1.5Gtexel/s or 24GFLOPs with texture filtering and DMA infrastructure
Memory	1GB LPDDR2
Operating System	Boots from Micro SD card, running a version of the Linux operating system
Dimensions	85 x 56 x 17mm
Power	Micro USB socket 5V, 2A

Connectors:

Ethernet	10/100 BaseT Ethernet socket
Video Output	HDMI (rev 1.3 & 1.4)
	Composite RCA (PAL and NTSC)
Audio Output	3.5mm jack, HDMI
USB	4 x USB 2.0 Connector
GPIO Connector	40-pin 2.54 mm (100 mil) expansion header: 2x20 strip
	Providing 27 GPIO pins as well as +3.3 V, +5 V and GND supply lines
Camera Connector	15-pin MIPI Camera Serial Interface (CSI-2)
JTAG	Not populated
Display Connector	Display Serial Interface (DSI) 15 way flat flex cable connector with two data lanes and a clock lane
Memory Card Slot	Micro SDIO

พอร์ต GPIO ของ บอร์ด Raspberry Pi 2 Model B

Raspberry Pi2 GPIO Header

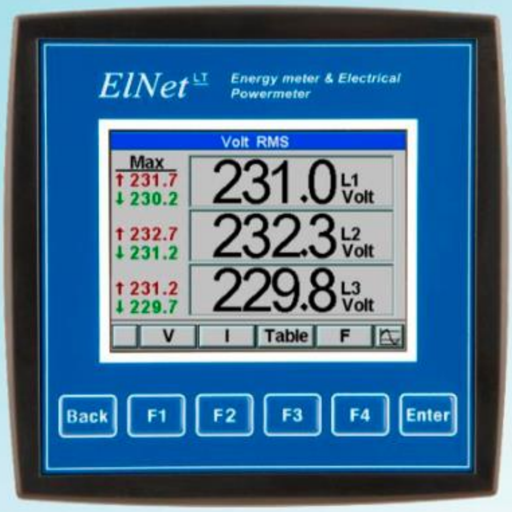
Pin#	NAME	NAME	Pin#
01	3.3v DC Power	DC Power 5v	02
03	GPIO02 (SDA1 , I²C)	DC Power 5v	04
05	GPIO03 (SCL1 , I²C)	Ground	06
07	GPIO04 (GPIO_GCLK)	(TXD0) GPIO14	08
09	Ground	(RXD0) GPIO15	10
11	GPIO17 (GPIO_GEN0)	(GPIO_GEN1) GPIO18	12
13	GPIO27 (GPIO_GEN2)	Ground	14
15	GPIO22 (GPIO_GEN3)	(GPIO_GEN4) GPIO23	16
17	3.3v DC Power	(GPIO_GEN5) GPIO24	18
19	GPIO10 (SPI_MOSI)	Ground	20
21	GPIO09 (SPI_MISO)	(GPIO_GEN6) GPIO25	22
23	GPIO11 (SPI_CLK)	(SPI_CE0_N) GPIO08	24
25	Ground	(SPI_CE1_N) GPIO07	26
27	ID_SD (I²C ID EEPROM)	(I²C ID EEPROM) ID_SC	28
29	GPIO05	Ground	30
31	GPIO06	GPIO12	32
33	GPIO13	Ground	34
35	GPIO19	GPIO16	36
37	GPIO26	GPIO20	38
39	Ground	GPIO21	40

Rev. 1
26/01/2014

http://www.element14.com

ข5. รายละเอียดข้อมูลของมิเตอร์วัดพลังงาน รุ่น Elnet LT

ELNet [LT] Energy meter & Electrical Powermeter



ELNet LT energy powermeter is a compact, multi functional, three-phase powermeter, especially designed to meet the stringent needs of power and energy measurement in any electrical installation. ELNet LT includes history data logging and supports standard communication protocols BACnet and Modbus with simple integration into Building Management Systems over RS485 or Ethernet TCP. An indispensable tool for the Building Engineer, it aids efficient use of electricity by showing Power Factor, Max and Min demand, Current in Neutral Line and Harmonics up to 64th.

Technical Data

Power Requirements:	90 ~ 250 VAC 110 ~ 280 VDC 60/50 Hz 9VA
Dimensions (HxWxD):	96 x 96 x 80 mm
Shipping Weight:	0.65 Kg.
Environmental:	
Operation.	-20 ~ +70 ℃
Storage.	-20 ~ +70 ℃
Humidity	0 ~ 95 RH% non-condensing
Front Panel Protection	IP64
Memory size:	Flash memory dedicated for 6 months of daily energy and additional 1MB memory.

Communication

RS485 port:	Up to 115200 bauds Modbus and BACnet
Ethernet (TCP/IP):	Optional & Web browser capability

Input & Output Rating

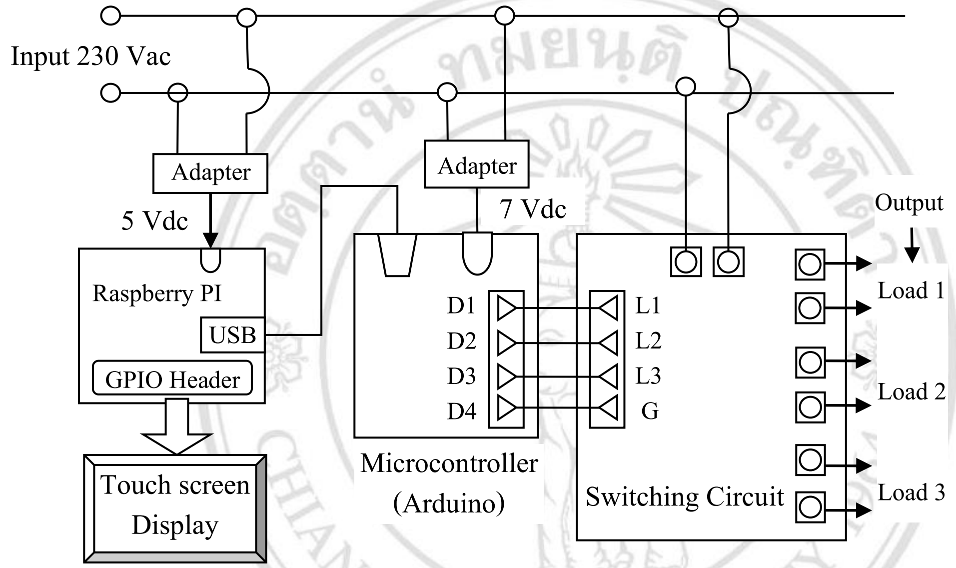
Accuracy:	Active energy 0.2% Reactive energy 0.2%
Voltage: Line-Line	0 ~ 950 VAC RMS
Line-Neutral	0 ~ 550 VAC RMS
Maximum	1000V RMS Continuous
Burden	< 0.06VA
Current: Rated	0-1 A or 0-5 A
Overload	50 A RMS Continuous
Withstand	100 A for 1 minute
Burden	< 0.05 VA
Display:	High resolution color LCD display 320x240 pixels
Maximum Input Voltage:	1000V
Maximum Input Current:	6A
Digital inputs:	2, 230VAC (ON)
Digital \ pulse output:	1, dry contact maximum load 250mA

CONTROL APPLICATIONS Ltd.
Supervision & control system
Tel: +972-3-6474998 Fax:+972-3-6474598 24a Habarzel St. Tel-Aviv, 69710, Israel

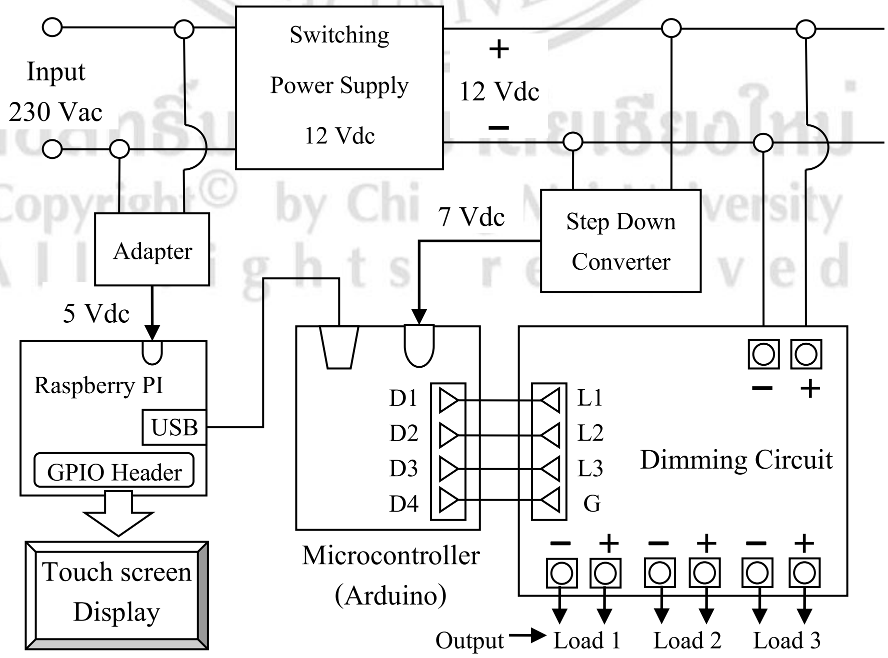
ภาคผนวก ค

Wiring Diagrams

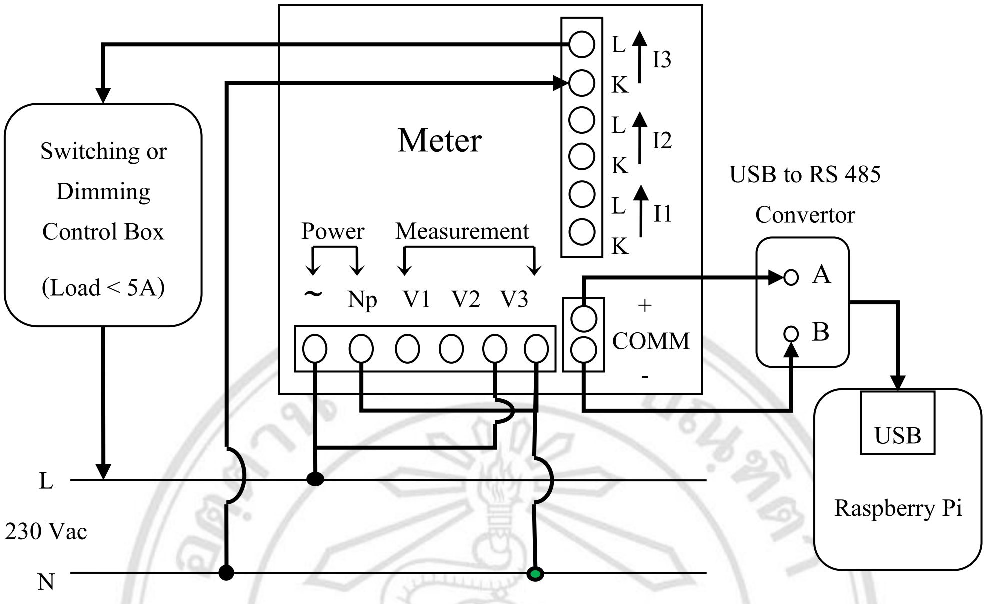
ค1. Switching control box diagram



ค2. Dimming control box diagram



ค1. Meter wiring diagram



ภาคผนวก ง

แบบสอบถามความพึงพอใจของผู้ใช้งาน
ระบบจัดการพลังงานไฟฟ้าแสงสว่างในอาคารพาณิชย์และบ้านพักอาศัย

แบบสอบถาม มี 2 ส่วน ประกอบด้วย

ส่วนที่ 1 ข้อมูลผู้กรอกแบบสอบถาม

ส่วนที่ 2 ความพึงพอใจของผู้ใช้บริการที่มีต่อระบบจัดการพลังงานไฟฟ้าแสงสว่าง

ส่วนที่ 1 ข้อมูลผู้กรอกแบบสอบถาม

1. เพศ	☐ ชาย	☐ หญิง
2. สถานที่ใช้งาน	☐ อาคารพาณิชย์	☐ บ้านพักอาศัย

ส่วนที่ 2 ความพึงพอใจของผู้ใช้บริการที่มีต่อระบบจัดการพลังงานไฟฟ้าแสงสว่าง

กรุณา ✔ ในระดับความพึงพอใจของผู้ใช้งานในส่วนของระบบจัดการพลังงานไฟฟ้าแสงสว่างที่ท่านเคยใช้งาน

2.1 ความแตกต่างระหว่างการใช้งานหลอดฟลูออเรสเซนต์และหลอด LED

☐ ไม่แตกต่าง

☐ แตกต่าง

คือ ....

2.2 ระบบที่มีการใช้งานเพียงฟังก์ชัน Occupancy control

รายการ	ระดับความพึงพอใจ		
	มากที่สุด	ปานกลาง	น้อยที่สุด
1. ประสิทธิภาพการทำงานของระบบ			
2. ผลกระทบต่อการทำงาน (ระบบส่งผลทำให้ผู้ใช้มีประสิทธิภาพการทำงานลดลง)			
3. ระบบใช้งานง่าย			
4. มีความทันสมัย			
5. ผลการประหยัดพลังงาน			
6. ค่าใช้จ่ายในการติดตั้งระบบ			

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2.3 ระบบที่มีการใช้งานเพียงฟังก์ชัน Time Scheduling

รายการ	ระดับความพึงพอใจ		
	มากที่สุด	ปานกลาง	น้อยที่สุด
1. ประสิทธิภาพการทำงานของระบบ			
2. ผลกระทบต่อการทำงาน (ระบบส่งผลทำให้ผู้ใช้มีประสิทธิภาพการทำงานลดลง)			
3. ระบบใช้งานง่าย			
4. มีความทันสมัย			
5. ผลการประหยัดพลังงาน			
6. ค่าใช้จ่ายในการติดตั้งระบบ			

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2.4 ระบบที่มีการใช้งานเพียงฟังก์ชัน Daylight Control

รายการ	ระดับความพึงพอใจ		
	มากที่สุด	ปานกลาง	น้อยที่สุด
1. ประสิทธิภาพการทำงานของระบบ			
2. ผลกระทบต่อการทำงาน (ระบบส่งผลทำให้ผู้ใช้มีประสิทธิภาพการทำงานลดลง)			
3. ระบบใช้งานง่าย			
4. มีความทันสมัย			
5. ผลการประหยัดพลังงาน			
6. ค่าใช้จ่ายในการติดตั้งระบบ			

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2.5 ระบบที่มีการใช้ทุกฟังก์ชันที่เหมาะสมร่วมกันเป็นระบบเดียว

รายการ	ระดับความพึงพอใจ		
	มากที่สุด	ปานกลาง	น้อยที่สุด
1. ประสิทธิภาพการทำงานของระบบ			
2. ผลกระทบต่อการทำงาน (ระบบส่งผลทำให้ผู้ใช้มีประสิทธิภาพการทำงานลดลง)			
3. ระบบใช้งานง่าย			
4. มีความทันสมัย			
5. ผลการประหยัดพลังงาน			
6. ค่าใช้จ่ายในการติดตั้งระบบ			

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2.6 ระบบที่มีการใช้งานเพียงฟังก์ชัน Daylight Control (ระบบสามารถปรับระดับแสงสว่างได้)

รายการ	**ระดับความพึงพอใจ**		
	มากที่สุด	**ปานกลาง**	**น้อยที่สุด**
1. ประสิทธิภาพการทำงานของระบบ			
2. ผลกระทบต่อการทำงาน (ระบบส่งผลทำให้ผู้ใช้มีประสิทธิภาพการทำงานลดลง)			
3. ระบบใช้งานง่าย			
4. มีความทันสมัย			
5. ผลการประหยัดพลังงาน			
6. ค่าใช้จ่ายในการติดตั้งระบบ			

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2.7 ระบบที่มีการใช้ทุกฟังก์ชันที่เหมาะสมร่วมกันเป็นระบบเดียว (ระบบสามารถปรับระดับแสงสว่างได้)

รายการ	**ระดับความพึงพอใจ**		
	มากที่สุด	**ปานกลาง**	**น้อยที่สุด**
1. ประสิทธิภาพการทำงานของระบบ			
2. ผลกระทบต่อการทำงาน (ระบบส่งผลทำให้ผู้ใช้มีประสิทธิภาพการทำงานลดลง)			
3. ระบบใช้งานง่าย			
4. มีความทันสมัย			
5. ผลการประหยัดพลังงาน			
6. ค่าใช้จ่ายในการติดตั้งระบบ			

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IEEE PES ISGT ASIA 2015
Innovative Smart Grid Technologies
3-6 November 2015
The Centara Grand & Bangkok Convention Centre
at Central World, Bangkok, Thailand
IEEE
PES
Power & Energy Society
PEA
MINISTRY OF ENERGY
TCEB
AIT
IEEE
TGGS
MEDIA

S 04: Building and Home Energy Management in Smart Grid I
Time: 13:00 – 15:00
Room Assignment: Lotus 13
Chairperson: Dr. Manisa Pipattanasomporn (Virginia Tech – Advanced Research Institute, USA)

Ref. No.	Title, Authors, Affiliation	Country of Origin	ISGT Asia 2015 reference code
S 04.1	**Building HVAC Load Profiling Using Energy Plus** *Dong Wang, Abhisek Ukil and Ujjal Manandhar* School of EEE, Nanyang Technological University, Singapore	Singapore	053
S 04.2	**Multi-Stage Scheduling for a Smart Home with Solar PV and Battery Energy Storage – A Case Study** *Batchu Rajasekhar and Naran Pindoriya* Electrical Engineering, Indian Institute of Technology Gandhinagar, India	India	079
S 04.3	**Intelligent Multi-Agent System for Smart Home Energy Management** *W. Li, T. Logenthiran and W.L. Woo* School of Electrical and Electronic Engineering Newcastle University, Singapore	Singapore	127
S 04.4	**An Intelligent Lighting Energy Management System for Commercial and Residential Buildings** *Siriporn Bannamas and Peerapol Jirapong* Department of Electrical Engineering, Chiang Mai University, Thailand	Thailand	166
S 04.5	**Laboratory Smart Home Energy Management System** *Ciprian Ionut PAUNESCU, Lucian TOMA, Mircea EREMIA* Department of Electrical Power Systems University POLITEHNICA of Bucharest, Romania	Romania	176

IEEE PES International Conference on

Innovative Smart Grid Technologies Asia 2015 (ISGT Asia 2015 Bangkok)

IEEE

IEEE PES Power & Energy Society

2015 ISGT Asia

IEEE ISGT ASIA 2015

4 - 6 November 2015

Centara Grand and Bangkok Convention Center at Centralworld

Pathumwan, Bangkok, Thailand

About the Conference

The IEEE PES Innovative Smart Grid Technologies 2015 Asian Conference, sponsored by the IEEE Power and Energy Society, will be held on 4-6 November 2015 in Bangkok, Thailand. The conference will be hosted by the IEEE PES Thailand Chapter.

ISGT Asia 2015 Bangkok will be a venue for stakeholders from the academia, electric utilities and the power industry to share and exchange experiences and new ideas which will contribute to the development of Smart Grid and related technologies.

ISGT Asia 2015 Bangkok will cover keynote addresses and panel discussion from distinguished personalities in Smart Grid. It is also expected to attract papers not only from Asia from around the world in the field of smart grid and related technologies. Deadline of full paper submission is 15 May 2015.

ISGT Asia 2015 Bangkok will also conduct tutorials on related topics. For more information, please contact the Conference Chair at isgtasia2015@ieee.org. More details are also available at the conference website, www.ieee-isgt-asia-2015.org.

Topics for ISGT Asia 2015 Bangkok

The following list is only indicative of the key thematic areas but will not be restrictive.

- Smart grid technologies (for power generation, transmission and distribution systems, and energy conversion and storage devices).
- Smart grid communication and information technologies
- Distributed generation and micro-grid
- Electric vehicle charging technology and system integration
- Micro-grid applications and islanding operation
- Smart grid measurements, protection, control and operation
- Physical, cyber and system security for smart grid
- Computation intelligence and IEDs for smart grids
- Sensing, communication and smart metering infrastructures
- Demand side management, smart buildings and home automation
- Diagnostics, self-healing and reliability of smart grids
- Power quality issues and FACTS devices
- Electricity markets, incentives, regulation and pricing
- Smart grid interoperability, standards and codes
- Demand response and management through smart grid technology
- Renewable energy integration and storage
- Smart grid planning, economic, environment and policy issues

An Intelligent Lighting Energy Management System for Commercial and Residential Buildings

Siriporn Bannamas and Peerapol Jirapong*
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*Levinson331@gmail.com

***Abstract*—This paper presents an intelligent lighting energy management system which is combined with six lighting control functions i.e. occupancy control, time scheduling, daylight control, task control, personal control and variable power shedding. There are two modes in the proposed lighting management system, which are the automatic and the personal control. Users can also control the system through the lighting management program and an internet web server. The lighting management system utilizing both natural and artificial light consists of the hardware, which is microcontroller and Raspberry Pi, and the software, which controls and manages the system. Furthermore, this paper proposes not only a method for choosing suitable functions in each area, but also a priority sequence method conforming to the two basic principles of efficiency in performance and effectiveness in light energy conservation. The experimental results showed that the proposed system could efficiently and effectively manage energy consumption. The system can be used to avoid energy waste, and saving energy consumption by a maximum of 68% in both switching and dimming control during typical days.**

***Index Terms*--daylight; energy savings; energy consumption; intelligent lighting system; lighting control; lighting system.**

I. INTRODUCTION

Energy is considered very important for modern life especially electrical power which is widely used for human activities. Every commercial and residential building also consumes a great deal of electrical energy through lighting systems. Therefore, energy management and conservation must be developed for reducing energy consumption in the systems during typical days. It can be clearly seen that controlling time and power is the most significant strategy to reduce energy consumed in the systems. A smart lighting system could be used to reduce energy consumption without affecting visibility and work effectiveness; moreover, it could increase convenience and safety [1].

According to lighting standards and legislation (EN12464-1) [2], any luminaries must be designated appropriately for the work environment. Selecting different types of lamps could affect light efficiency and electrical energy utilization [3]. A lighting control system was proposed to manage power consumption by regulating luminance levels. Light could be controlled by dimming the luminaries and reducing lamp usage by dividing rooms into small sections [4]. There was a case study of an advanced lighting control system designed for classrooms. One was arranged only with on/off switching control without changing the luminaries. The other could change the luminance levels with a dimming control. Test results showed that the dimmer system installed in classrooms could avoid energy waste for unoccupied daylight hours [5].

Arrival time of trains and on/off switching lighting control could be utilized in an automated system. However, this method was only suitable for some locations for a certain period of time [6]. An automatic switching control utilizing a web camera was developed for controlling light to illuminate. When it did not detect any movement, light would be automatically turned off to save energy [7]. Other research investigated passive infrared (PIR) sensors, which could be used to detect movement in a space. The advantages of PIR sensor are low cost and small size; moreover, it consumes low power and requires little maintenance [8]. Another study used pressure sensors installed at every chair to detect users. The result showed that the electric power usage was decreased by 30%. However, the pressure sensor is difficult to install and more expensive than PIR sensors [9].

One of the interesting studies was involved in separating room space into three areas by distance from window and utilized sunlight for each divided areas. Less luminance was required for any working areas which were nearer the window but more if farther away. This method could decrease energy consumption and save money [10]. Finally, a lighting control system was developed for controlling power consumption in buildings. When the power usage reached the maximum level, some unnecessary luminaries would be dimmed to reduce power consumption [11].

Lighting control systems, which were automatically controlled by daylight and movement, have been used in many smart homes. Moreover, people could also control the systems directly from both personal computers and remote control systems [12] or even though their own smart phone with an Android application [13]. Another lighting control system in a smart building was proposed to control a lighting system depending on the principle of occupancy in order to reduce lighting usage when a room was unoccupied [14].

As mentioned above, most of the effective methods were developed independently and many researchers applied only some of them in a general lighting system, even though these methods could be integrated into an efficient system to manage energy consumption effectively. Therefore, the purpose of this study was to develop an intelligent lighting energy management system which combines six lighting control functions, i.e. occupancy control, time scheduling, daylight control, task control, personal control and variable power shedding, into a unique system for saving electrical energy consumption in commercial and residential buildings. Each function could be chosen to operate with the others which depend on suitable working environments, activities and task equipment to find out the most effective way to manage and conserve energy.

II. LIGHTING ENERGY MANAGEMENT SYSTEM

The main concept of the proposed lighting management system is an integration of the six major functions that can be selected to use for reducing electrical energy consumption. Each function is described in the following sections.

A. *Function 1: Occupancy Control*

This function is an automatic lighting management system which detects occupancy inside a room. Light will be automatically turned on when detecting movement of an occupant and turned off after the last occupant leaves the room. Passive infrared sensors were chosen for this task. For wide spaces and high security situations, the use of web cameras is suggested.

B. *Function 2: Time Scheduling*

Time schedule is the most noticeable feature in this function. Light can be programmed to automatically turn on or off for all required periods of time.

C. *Function 3: Daylight Control*

This function uses the benefits of sunlight. A room is divided into multiple sections based on the distance from windows. Each separate section will get a different amount of sunlight. The sections near the windows which have already received a great deal of bright light will automatically dim the light, while in more distant areas luminance levels need to be increased. According to this scheme, power usage can be saved and the light level in each section is still controlled by the recommended luminance standard in EN 12464-1 [2].

D. *Function 4: Task control*

This function divides the room area into small sections. Light can be switched on only in specific working areas such as a table, a notification board or a bathroom mirror. In other words, the light will be turned on only in the area where people are functioning.

E. *Function 5: Personal Control*

Users can control the lighting system as required through using a computer program. This flexibility can help users work more conveniently. Furthermore, if this function is recommended being applied in large buildings, the energy conservation will be more effective.

F. *Function 6: Variable Power Shedding*

This function calculates maximum power required for a building. When the total power usage is equal to the default setting, the program will set off an alarm to warn the users as well as showing the quantity of power consuming. Then, the users can choose to switch off unnecessary luminaries or allow the system to cut off automatically.

The suitable default power setting is calculated by load factor which refers to the working time. During a typical day, appropriate load factor should be at 80%.

III. SYSTEM DESIGN AND CONSTRUCTION

The intelligent lighting energy management system consists of two parts: hardware and software. The hardware is comprised of two control systems: switching control and dimming control. The hardware includes switching circuit, dimming circuit, motion sensors, light meters, microcontroller and Raspberry Pi. The software used was the Gambus program in Raspberry Pi. The operating station receives and manages any orders from users and data from a power/energy meter. Users can control the light operation through a touch screen display. Furthermore, the program can control both luminance levels and time to switch on or off in each zone. In addition, the users can control the system through an internet web server.

A. *Equipment*

Equipment used in this proposed system consists of various components as follows:

- Fluorescent lamps (36 Watt, 230 V_{ac}) and LED lamps (14 Watt, 12 V_{dc}) which have similar luminance.
- Switching power supply used for supplying (12 V_{dc}, 29 A) voltage to LED lamps.
- Power/energy meter used for measuring power which is consumed in the system.
- USB to RS-485 converter used for connecting an RS485 interface with USB.
- Arduino UNO R3 with 20 digital input/output pins used for controlling the system.
- Raspberry Pi is used as the operating station which receives and manages data metering and orders from a user.
- Ambient Light Sensor Module (BH1750FVI) is a digital Ambient Light Sensor IC for I2C bus interface. It is possible to detect between 1-65535 lux, and small measurement variations (+/-10%).
- PIR motion sensors are used for detecting motion from pets or humans from about 6 meters away. They are small, inexpensive, low-powered and easy to use.

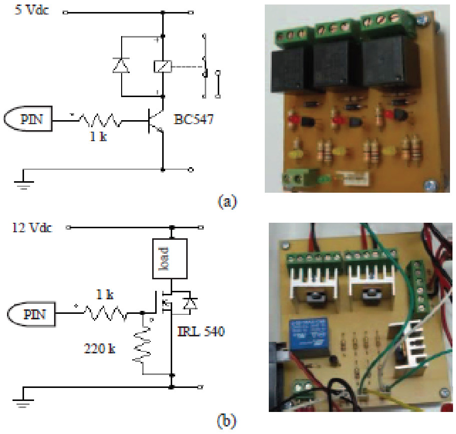

Figure 1. Circuit diagrams. (a) Switching control for fluorescents. (b) Dimming control for LED lamps.

B. Circuits

Two circuits were used in this experiment. One was the switching circuit used for controlling on/off in the fluorescents. The other was the dimming circuit used for controlling the LED lamps which were supplied by the switching power supply.

In addition, the LED lamps have full dimming capabilities; as a result, they are compatible with the dimming control system. In addition, their life expectancy is not affected by frequently turning them on/off, and the LED lamps can help reduce carbon dioxide emissions. On the other hand, dimming controls are not recommended for the fluorescents because effective dimming ballasts that can reduce energy are very expensive.

Figure 1 (a) shows the switching circuit. The simple circuit operates switching on/off utilizing relays when the system is in the automatic mode. Figure 1 (b) shows the dimming circuit. The simple dimming circuit uses MOSFET (IRL540) to control voltage across lamps with pulse-width modulation (PWM). The PWM waves can control different levels of light intensity from 0% to 100%. The luminance levels have five different values of light output: 0%, 25%, 50%, 75% and 100%. This circuit is also used to control the LED lamps.

C. Operating station

The Gambus program is a graphic application program used for designing the Graphical User Interfaces (GUI) of lighting management programs. It can also link to the MySQL database, in which all data such as current, voltage, power and command of lighting management system is kept. The program manages and checks the operating orders from the users in the database. Then, it transmits the commands to activate the microcontroller to operate lights in the system. The users can control luminance levels and report load profiles through the GUI.

IV. System Operation and Control

The proposed six functions and system equipment were chosen by cost and suitability, and they were utilized in each function depending on location, working environment, installation, cost, user satisfaction and compatibility. It is important that users consider which functions are effectively compatible with other functions to avoid overlapping control. The next step is selecting the most suitable functions for each investigated area. Figure 2 shows the sequence of the steps used in selecting functions. Then, the most suitable functions will be integrated to work interactively as a unique system.

Figure 3 shows the steps of the priority sequence method. The occupancy control function interacts with time scheduling. Some unnecessary lights will be turned off to save energy by the occupancy control, whereas the time scheduling

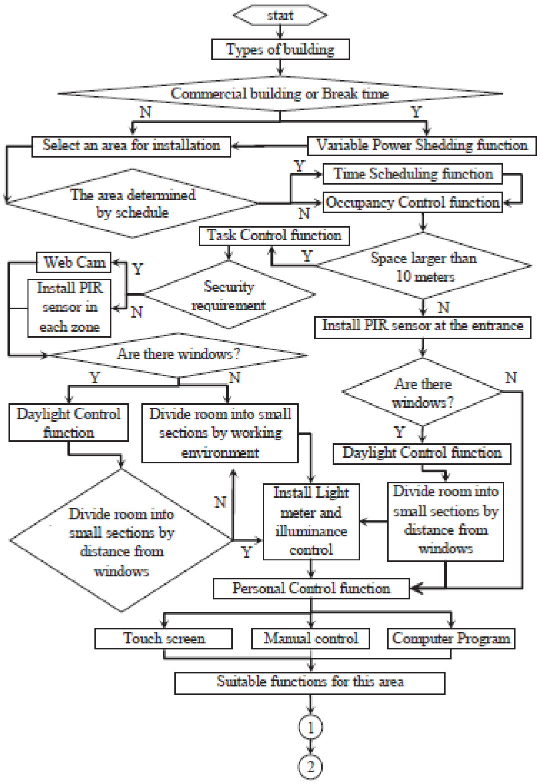

Figure 2. Flow chart of selecting suitable functions for the intelligent lighting energy management system.

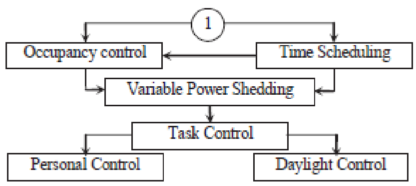

Figure 3. Flow chart of lighting control system.

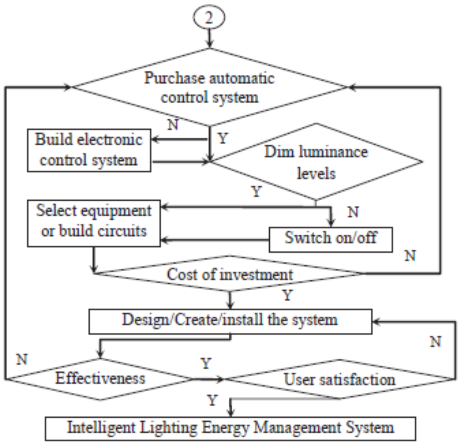

Figure 4. Steps to build the intelligent lighting energy management system

function is more suitable for some working areas determined by schedule. Each investigated area is timed to turn off at a specific time, but if people are still detected in the room, the time control will be overridden and light will stay on. The system further calculates the total power consumption of the building and compares it with the power setting to warn users when it reaches the maximum level. Next, the areas are divided into smaller sections. Each section will be dimmed based on luminance levels. The luminance levels depend on two factors. One is user operation and the other is the level of sunlight. After that, the system will be controlled sequentially according to the priority of each function. This priority sequence method will make the system easier to control, more effective in saving energy and have fewer malfunctions in operation.

Figure 4 shows the final steps used to complete the lighting management system. After selecting the suitable functions and designing a framework using the priority sequence method, the system can be controlled by two modes: the manual mode and the automatic mode. Most of the systems operate automatically to help the users work more efficiently.

V. Case Study

To investigate the efficiency and effectiveness of the proposed lighting management system, an experiment was implemented in an 8 m × 8 m test room, including two different window sizes: 5 m wide × 2 m high and 1 m wide × 2 m high. There were nine lamps installed symmetrically as shown in Figure 5. There were three lighting systems consisting of the manual switching system, the lighting management system with fluorescent lamps, and the lighting management system with LED lamps set up in the same room (Figure 6).

There were seven case studies with different scenarios classified by lighting control functions, lighting control strategies, and type of lamps as shown in Table I. Case 1 was prepared as the baseline using manual switching control. In cases 2 to 5, the lighting management systems were arranged using automatic on/off switching controls. In cases 6 and 7, the dimming controls were added to adjust the luminance levels in the system. The fluorescent lamps were tested only in cases 1 to 5, while the LED lamps were tested in cases 1 to 7. The monitoring hours of the room were from 09:00 to 16:00. The additional details of each case study are further described below the Table I.

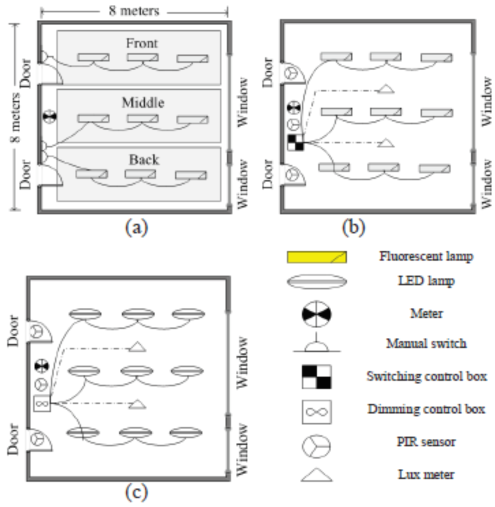

Figure 5. The test room with different light management settings: (a) the normal room with manual switches; (b) the lighting management system with fluorescent lamps; (c) the lighting management system with LED lamps.

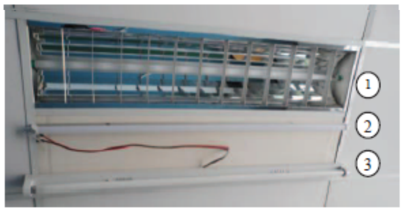

Figure 6. The actual test room with three systems (1) the manual switching system, (2) the fluorescent system, and (3) the LED system

TABLE I. FUNCTIONS USED IN EACH CASE STUDY.

Case	Function *						Remark
	1	2	3	4	5	6	
1							Fluorescents and LED lamps (switching control)
2	✓						
3		✓					
4			✓				
5	✓	✓	✓	✓	✓	✓	
6			✓				LED lamps (dimming control)
7	✓	✓	✓	✓	✓	✓	

✓ indicates the function(s) used in each case study
* Function 1: occupancy control Function 2: time scheduling
Function 3: daylight control Function 4: task control
Function 5: personal control Function 6: variable power shedding

Descriptions of the case studies:

Case 1: The baseline using only the manual switching control without the proposed lighting management system.

Case 2: The lighting management system will operate automatically when the presence of people inside the room (room occupancy) is detected by the PIR sensors.

Case 3: The system will automatically activate and deactivate 5 minutes, before and after work schedules, respectively. The working hours in the room are divided into two periods: 09:30 to 12:00 and 13:00 to 15:00.

Case 4: The system will be automatically shut down when the average natural luminance in the area exceeds 300 lux.

Case 5: All six functions are integrated to operate as one unique system. Moreover, the working hours in the room are still divided into two periods: 09:30 to 12:00 and 13:00 to 15:00. However, the users are not allowed to use maximum power during the break time, which starts between 12:00 to 13:00 and 15:00 to 16:00. During these periods, the system is set at 80% of the maximum power to limit power usage.

Case 6: This case operates similarly to case 4, but the luminance can be dimmed to five levels.

Case 7: This case operates similarly to case 5, but the luminance can be dimmed to five levels.

The power usage in each case study was recorded every 5 minutes, and each case was monitored for 3 days. Then, the total energy consumption was averaged per day.

VI. Implementation Results

Table II shows the average energy consumption (Wh/day) which were measured in each case study during a typical day. According to the results, the switching control system of both fluorescent and LED lamps (in cases 2 to 5) managed by the proposed functions consumed energy less than the system without control (in case 1). Similarly, in cases 6 and 7 the dimming control of LED lamps also consumed less energy than case 1 as well. Therefore, the results show whether the system with the switching and/or the dimming control can reduce energy consumption effectively.

TABLE II. Average Energy Consumption in Each Case Study

Type of lamp	Average Energy (Wh/day)						
	Without control	Switching control				Dimming control	
	Case 1	*Case 2*	*Case 3*	*Case 4*	*Case 5*	*Case 6*	*Case 7*
Fluorescent	3,027	2,440	2,346	2,180	1,559	-	-
LED	961	736	760	729	422	529	308

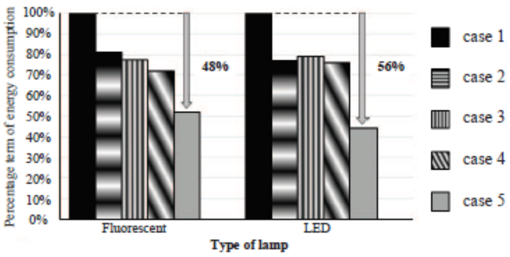

Figure 7. Comparision of percent energy savings in different case studies using the switching control system.

In case 1, when the LED system was compared with the fluorescent system, the interesting point is that approximately 2,066 W or up to 68% of daily energy consumption will be conserved since the LED lamps usually consume less electric power than the fluorescents.

As shown in Figure 7, case 5 of both lamps of the switching control system, which is considered the proposed efficient lighting management system, consumes the least amount of energy when compared with case 1 to 4. Moreover, the total power consumption of the proposed system during a typical day also decreases energy consumption by up to 48% in the fluorescents and 56% in the LED lamps when compared with case 1.

However, it is noticeable that the average energy consumption in cases 2 to 4 with the LED lamps is dissimilar to the results of the fluorescent lamps due to differences in daily usage and activities. Moreover, the actual energy consumption can vary according to the period of time spent in each activity and the suitability of each function used in each area.

In Figure 8 the average percent energy consumption of the LED lamps with dimming control are compared with case 1. As seen from the chart, it is obvious that the dimming control can reduce the energy usage more effectively than the switching control. For example, the luminance level in case 6 which is changeable based on the daylight availability can save energy by up to 34% when compared with case 4. Also, the proposed intelligent lighting system in case 7 consumes by far the least electrical power up to 12% when compared with case 5.

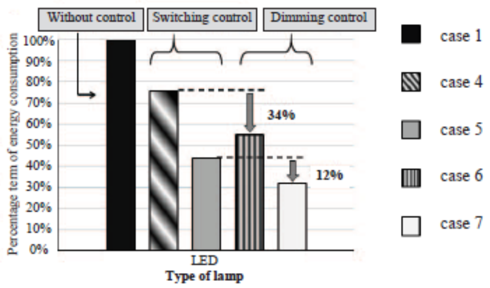

Figure 8. Comparision of percent energy savings in different case studies using the dimming control system.

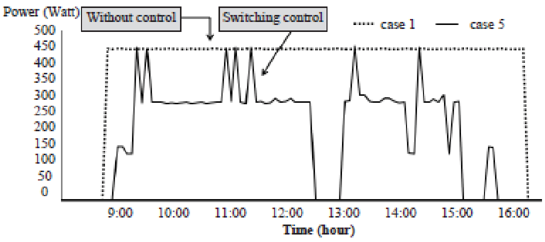

Figure 9. The example of the fluorescent system load profiles shown in W in the baseline case (case 1) compared with the proposed system (case 5 with the switching control)

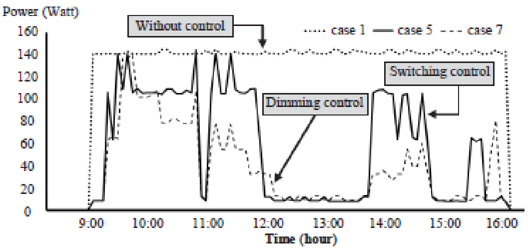

Figure 10. The LED system load profiles shown in W of the baseline case (case 1) compared with the optimal proposed system (case 7 could change the luminance but case 5 could not)

Figure 9 shows the example of the fluorescent system load profiles. The vertical axis represents power (Watt), and the horizontal axis represents working time (hour). The load profiles were recorded from 9:00 to 16:00. In case 1, the electric power usage stayed constantly because lights had been turned on continuously for seven hours. On the other hand, the electric power shown in case 5 was not stable because the lighting system could be controlled to switch on/off automatically depending on the users' actual needs and the natural luminance during typical days to avoid unnecessary energy waste.

Figure 10 shows the example of the LED system load profiles. In case 5 the graphs of both fluorescents and LED lamps power usage were similar. Furthermore, when the load profiles are compared, it can be seen that the lighting control system which can adjust the luminance levels based on the daylight availability (case 7) uses less electric power than case 5.

The switching control system is considered one of the effective ways for both fluorescents and LED systems to manage energy consumption. However, the dimming control system was proven to be far more efficient and effective than the switching control system.

VII. CONCLUSIONS

The proposed intelligent lighting energy management system in both automatic and manual control modes was implemented in an actual room. The six effective lighting control functions, consisting of the occupancy, time schedule, daylight control, task control, personal control and variable power shedding, were applied and integrated into one unique system. The luminance levels were controlled by the suitable working environments, activities and system equipment. Our research found that the dimming control system together with the adjustment of the luminance levels could conserve more energy than the switching control system. However, the proposed systems of the switching control (both fluorescent and LED system) and the dimming control (only the LED system) were shown to work efficiently and effectively in terms of great performance and energy savings, and have potential to use in actual commercial and residential buildings.

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ประวัติผู้เขียน

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ทุนการศึกษา ได้รับทุนอุดหนุนการวิจัยจากกองทุนเพื่อส่งเสริมการอนุรักษ์พลังงาน

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