Light Emitting Diode

Guideline for Using the Easy Estimation Tool to Calculate Luminous Flux

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The part number NFSW757D-V1 and NFSL757D-V1 in this document are the part number of Nichia's products, and do not have any relevance or similarity to other companies' products that may have trademark rights.

1. Overview

This application note describes the guidelines to estimate the optical characteristics (luminous flux/efficiency) of LED-mounted fixtures (tubes and down lights) using the "Easy Estimation Tool." Please refer to the "Easy Estimation Tool Guide" for detailed usage of the estimation tool.

2. Structure of a Typical LED Retrofit Lamp

2.1. Determination of Product Specifications

First of all, determine the target values for product specifications such as the luminous flux and the consumption power. Regarding the luminous flux and the efficiency, take the luminous flux decrease due to the optical cover into account to set their target values. The operating voltage/current are sometimes specified depending on the standard which applies to the product; in such a case, select the appropriate power supply to make it possible to operate the LEDs within the standard.
We designed the LED tube in accordance with "JEL801" specified by the Japan Lighting Manufacturers Association.

Target Values

Outline:	1,200mm
Luminous Flux:	2,300lm or more
Efficiency:	145lm/W or more
Color Temperature:	5,000K
Average Color Rendering Index (Ra):	80 or more
Input Power:	Voltage; DC45 to 95V, Current; 350mA in accordance with JEL801

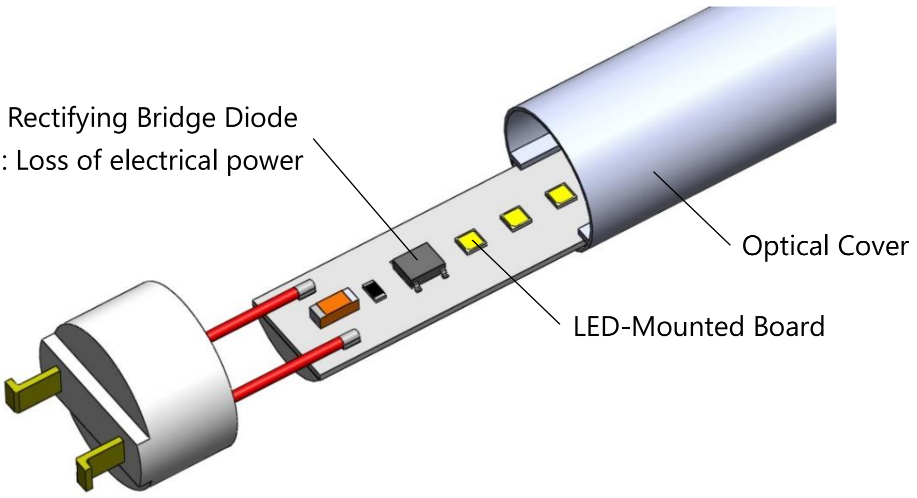

Figure 1. LED Tube Structure

2.2. Calculation with Easy Estimation Tool

Fill out the information in each item in the simulation tool.

2.2.1. LED Series and Model

Select the LED "Series" and "Type" in the simulation system (cf. Enclosed in blue 1 in Figure 2). Here is only one estimation example using NFSW757D-V1. In fact, in each Excel spreadsheet, there can be found the calculation results for five types at a time, where you will be able to compare values among them.
As described in Section 2.1, the target value of the color rendering index is Ra>80. Therefore, we chose R8000 for the simulation.

2.2.2. Parameters

Fill out the parameters which are necessary to estimate the optical characteristics (cf. Enclosed in blue 2 in Figure 2).

Table 1. Input Information for the Simulation

Item	Note	Input Examples
Target Flux	Target values of luminous flux	2,400lm (Target; 2,300lm+margin)
Color Rank	LED's color rank	For 5,000K, choose sw50.
Junction Temperature: T_J	Estimated LED's junction temperature	50°C, as reference to LED tubes with the same power/structure
Optical Efficiency Loss	Output loss due to optical covers, etc.	Fill out the luminous flux decrease rate resulting from the cover; i.e. 10%
Electrical Efficiency Loss	Power consumed in the circuits other than LEDs'	Fill out 3.7%; consumed by the rectifying bridge diode
LED Multiple	Quantity of LEDs used for the product	Fill out arbitrary numbers; they should be corrected later.

2.2.3. Estimation of Amount of LEDs

When the maximum input current is filled out in "Forward Current I_{FP}" (Enclosed in blue 3 in Figure 2), the characteristics can be calculated at each specific range (cf. Enclosed in red in Figure 2). Please note that the input I_{FP} below the table is the value for a single LED.
Next, the amount of LEDs (LED Multiple) can be calculated so that the LED tube's target values of the luminous flux, the power consumption, and the optical efficiency can be achieved at a specific input current.
Let us simulate the LED multiple using 757D-V1 as follows:

1) Determine the current applied to each LED which accomplishes the target efficiency (145lm/W or more), judging from the obtained values of "lm/W" (cf. Enclosed in red in Figure 2). As shown in the values in the table, the luminous efficiency of the LED tube will achieve 145lm/W or more unless the input current exceeds I_{FP} =65mA.
   The lower the current is applied to the LEDs, the higher the efficiency of the tube increases, on the basis of the LEDs' characteristics.

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The “LED Multiple (quantity of LEDs)” does not have to be determined at this point, since it is not related with the efficiency of the LED tube.

2) Based on the estimated maximum input current (I_{FP} =65mA) and the output current (350mA) of the power supply, the current applied to each LED will be I_{FP} =35mA. Then, the drive circuit can be obtained as follows: 350mA / 35mA = 10 parallel circuits

3) Assuming that the LEDs are connected in 10 parallel circuits, let us determine the “LED Multiple”, increasing it by 10 pieces. The “LED Multiple” should achieve the target luminous flux of 2,400lm at I_{FP} =35mA. The luminous flux will be 2,473.9lm, when the quantity of LEDs is 160 pieces, which accomplishes the target luminous flux. Thus, the quantity of LEDs needs to be 160 pieces; 16 series and 10 parallel for an LED tube.

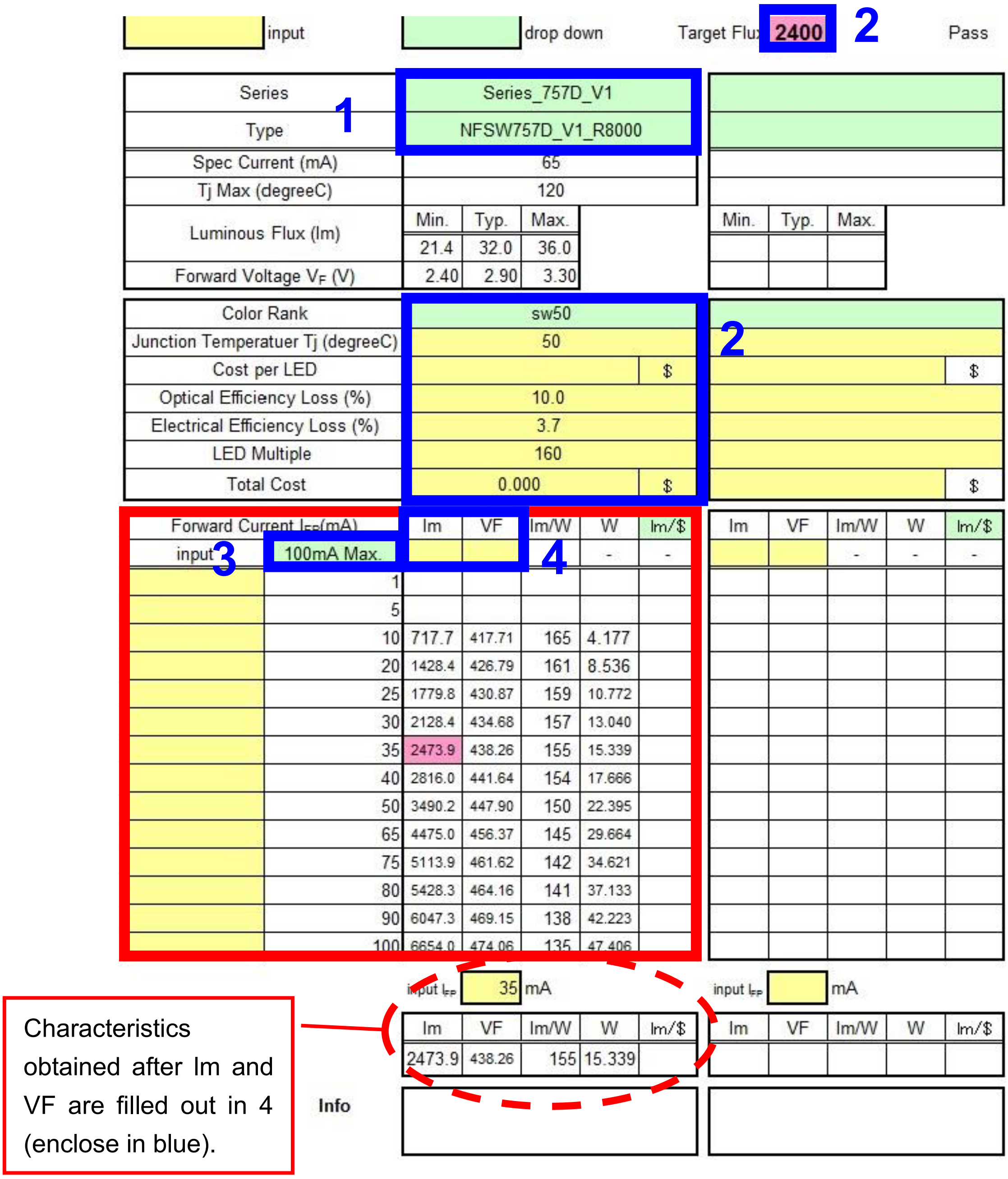

Figure 2. Example of Calculation

2.3. Impact of Variation in the Luminous Flux on the Simulation

In the Easy Estimation Tool, typical values of the luminous flux/forward voltage specified for each LED type are used. Therefore, the luminous flux and the forward voltage vary even within the same rank.
When you fill out “lm” or “VF” (Enclosed in blue 4 in Figure 2), the LEDs’ characteristics can be calculated at the rated luminous flux/forward voltage (rated current). Then, you can obtain the minimum/maximum luminous flux/power (efficiency) of the LEDs installed in the tube. Be sure to confirm whether the minimum/maximum values are within the tolerance specified for the LED tube.

2.4. Preparation of LED Tube

We prepared a sample LED tube in accordance with the specifications determined through Section 2.1 and the characteristics calculated through Section 2.2. The LED specifications are as follows:

LED Specifications

Part No.:	NFSW757D-V1
Quantity:	160 pcs. (16 series and 10 parallel)
Luminous Flux:	31.25lm at 65mA applied to each LED (average value of 50 sampled-out pieces)
V_F:	2.93V at 65mA applied to each LED (average value of 50 sampled-out pieces)
Color Rank:	sw50 (5,000K)
Color Rendering Rank:	R8000 (Ra>80)

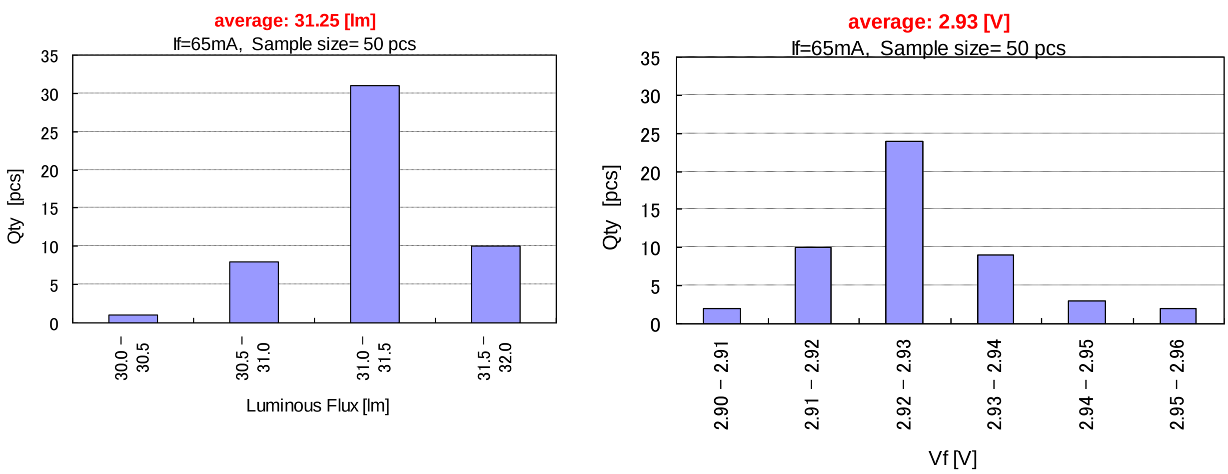

Figure 3. LED’s Luminous Flux and VF (50 Sampled-out LEDs)

3. Evaluation of LED Tube Performance

The performance of the LED tube prepared in Section 2.4 has to be evaluated to confirm whether there is any significant difference between the actual values and the calculation. If there are any significant differences between them, it is necessary to review the parameters and recalculate the values.

3.1. Electrical/Optical Characteristics

The LED tube's power consumption is measured with a power measurement device and its luminous flux is measured with a sphere. Be sure to operate the LED tube until the heat is saturated and until the measurement results stabilize.

Measurement Results of Sample LED Tube

Power Consumption:	16.1W
Luminous Flux:	2,412lm
Efficiency:	150lm/W

3.2. Thermal Factor

3.2.1. Thermal Distribution

The heat distribution on the board is measured with a thermometer while the heat is saturated in the tube. If the thermal distribution is inhomogeneous, the LEDs' junction temperatures may vary depending on their location. Then, the LEDs' brightness may vary due to their thermal characteristics. Consequently, it is difficult to evaluate the LED tube characteristics.

As seen in Figure 4, there is no problem in the thermal distribution in the LED tube: the heat is homogeneously dissipated in the tube.

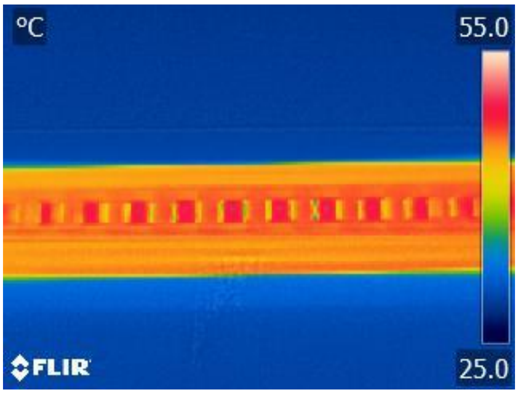

Figure 4. Thermal Distribution in the LED Tube

3.2.1. Thermal Distribution

The junction temperature can be calculated by the soldering temperature (cf. Equation 1). When measuring the soldering temperature, saturate the heat within the tube after fixing the thermocouples to the LED leads with solder or adhesive agent.

Be sure to measure the soldering temperature in the finished product; in a closed environment within the housing by attaching an optical cover, etc.

Thermal design of LED tubes should not exceed the LEDs' absolute maximum rating.

LED Junction Temperature

$$T_J = T_S + R_{\Theta JS}\,W \qquad \text{(Equation 1),}$$

where T_S: Soldering temperature (°C),

$R_{\Theta JS}$: Thermal resistance from the LED die to the Ts measuring point (°C/W)

W: Power supply to each LED; $I_F \times V_F$ (W)

Measurement Results of Sample LED Tube

T_S (Soldering Temperature): 46.2°C

T_J (Junction Temperature): 46.2°C + 13°C/W × 0.1W = 47.5°C

where $R_{\Theta JS}$= 13°C/W * Specified for the LEDs

W= 2.9V × 35mA = 0.1W

3.3. Comparison between the Measured/Calculated Values

Let's compare the measured values and the calculated ones.

Table 2. Comparison of Measurement and Calculation

	Calculated	Measured	Difference
Tube Luminous Flux	2,474lm	2,412lm	-2.5%
Tube Efficiency	155lm/W	150lm/W	-3.2%

Both the tube luminous flux/efficiency met the target values; however, the measured values were below the calculated ones. The difference of 5lm/W is relatively large, which may affect the LED tube performance. Therefore, the measurement conditions should be reviewed and the measurement results should be evaluated again.

The junction temperature was 47.5°C, based on the measurement results. According to the LED specifications (cf. Section 2.4), the luminous flux and the V_F were 31.25lm and 2.93V per LED, respectively. Therefore, the measurement parameters were corrected as follows:

Table 3. Parameters and Measurement Values

	Before Corrected	After Corrected
Electrical current applied to each LED	35mA	35mA
Junction Temperature	50.0°C	47.5°C
Optical Loss	10%	10%
Electrical Loss	3.7%	3.7%
Qty of LEDs	160pcs.	160pcs.
Luminous Flux per LED	32.0lm (Typ.)	31.25lm
V_F per LED	2.90V (Typ.)	2.93V

input	drop down	Target Flux	2400	Pass

Series	Series_757D_V1		
Type	NFSW757D_V1_R8000		
Spec Current (mA)	65		
Tj Max (degreeC)	120		
	Min.	Typ.	Max.
Luminous Flux (lm)	21.4	32.0	36.0
Forward Voltage V_F (V)	2.40	2.90	3.30

Color Rank	sw50	
Junction Temperatuer Tj (degreeC)	47.5	
Cost per LED		$
Optical Efficiency Loss (%)	10.0	
Electrical Efficiency Loss (%)	3.7	
LED Multiple	160	
Total Cost	0.000	$

Forward Current I_{FP}(mA)		lm	VF	lm/W	W	lm/$
input	100mA Max.	31.25	2.93	-	-	-
	1					
	5					
	10	703.2	421.40	161	4.214	
	20	1399.4	431.15	156	8.623	
	25	1743.7	435.47	154	10.887	
	30	2085.2	439.48	152	13.184	
	35	2423.7	443.22	150	15.513	
	40	2758.9	446.74	149	17.869	
	50	3419.4	453.19	145	22.660	
	65	4384.2	461.85	141	30.021	
	75	5010.2	467.20	138	35.040	
	80	5318.2	469.80	136	37.584	
	90	5924.6	474.90	133	42.741	
	100	6519.1	[illegible]	131	[illegible]	

input I_{FP} 35 mA

lm	VF	lm/W	W	lm/$
2423.7	443.22	151	15.513	

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	Min.	Typ.	Max.

lm	VF	lm/W	W	lm/$
		-	-	-

input I_{FP} mA

lm	VF	lm/W	W	lm/$

Figure 5. Re-calculation of LED Tube

Let us compare the recalculation results and the measurement ones.

Table 4. Comparison of Recalculation Results and Measurement Results

	Calculated	Measured	Difference
Tube Luminous Flux	2,424lm	2,412lm	-0.5%
Tube Efficiency	151lm/W	150lm/W	-0.7%

The differences in both the tube luminous flux/efficiency became much smaller; therefore, the LED tube was designed in accordance with the calculation after the parameter correction.

4. Estimation for LED Down Light

4.1. Determination of Product Specifications

First of all, determine the target values for product specifications such as the luminous flux and the consumption power. We designed an LED down light to achieve the following specifications.

Target Values

Luminous Flux:	370lm or more
Color Temperature:	2,700K
Average Color Rendering Index (Ra):	80 or more
Circuit:	12 LEDs connected (4series and 3parallel)
Input Power:	DC 330mA (The electrical current of 110 mA is flown into per LED, since 3 LEDs are connected in parallel.)

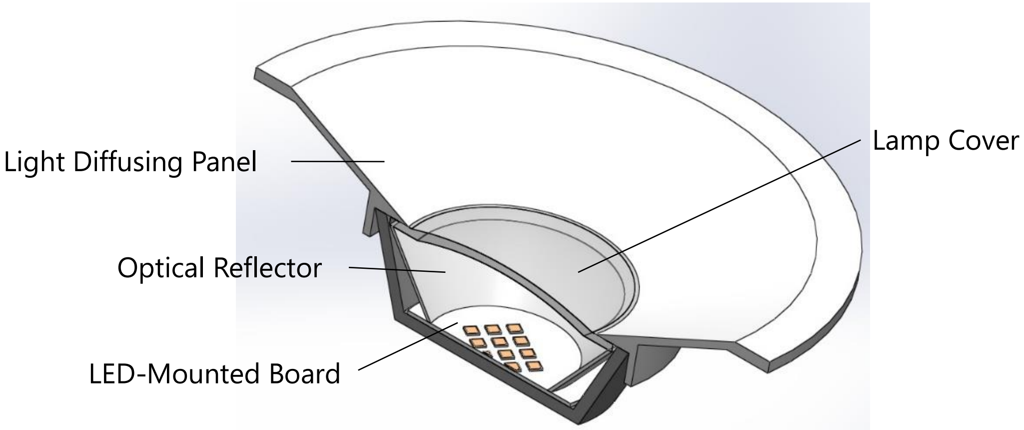

Figure 6. LED Tube Structure

4.2. Calculation with Easy Estimation Tool

Fill out the information in each item in the simulation tool as described in Section 2.2.

4.2.1. LED Series and Type

We used one of the same series with a different color (NFSL757D-V1) for the LED down light.
As described in Section 4.1, the target value of the color rendering index is Ra>80. Therefore, we chose R8000 for the simulation.

4.2.2. Parameters

Fill out the parameters which are necessary to estimate the performance.

Table 5. Input Information for the Simulation

Item	Note	Input Examples
Target Flux	Target values of luminous flux	370lm
Color Rank	LED's color rank	For 2,700K, choose sw27.
Junction Temperature: T_J	Estimated LED's junction temperature	50°C, as reference to LED down light with the same power/structure
Optical Efficiency Loss	Output loss due to optical covers, etc.	Fill out the luminous flux decrease rate resulting from the cover; i.e. 19.3%
Electrical Efficiency Loss	Power consumed in the circuits other than LEDs'	No electrical loss
LED Multiple	Quantity of LEDs used for the product	12 pcs.

4.2.3. Calculation

Figure 7 shows that the luminous flux meets (reaches) the target specifications; 370lm.

input	drop down	Target Flux	370	Pass	

Series	Series_757D_V1	
Type	NFSL757D_V1_R8000	
Spec Current (mA)	65	
Tj Max (degreeC)	120	

	Min.	Typ.	Max.	Min.	Typ.	Max.
Luminous Flux (lm)	18.0	25.9	30.3			
Forward Voltage V_F (V)	2.40	2.90	3.30			

Color Rank	sw27			
Junction Temperatuer Tj (degreeC)	50			
Cost per LED		$		$
Optical Efficiency Loss (%)	19.3			
Electrical Efficiency Loss (%)				
LED Multiple	12			
Total Cost	0.000	$		$

Forward Current I_{FP}(mA)		lm	VF	lm/W	W	lm/$	lm	VF	lm/W	W	lm/$
input	200mA Max.			-	-	-			-	-	-
	10	38.6	31.33	123	0.313						
	15	57.9	31.68	122	0.475						
	20	77.3	32.01	121	0.640						
	30	115.5	32.60	118	0.978						
	40	153.1	33.12	116	1.325						
	50	189.8	33.59	113	1.680						
	65	242.9	34.23	109	2.225						
	75	277.1	34.62	107	2.597						
	80	293.8	34.81	105	2.785						
	100	358.9	35.55	101	3.555						
	120	421.9	36.28	97	4.354						
	150	515.9	37.38	92	5.606						
	180	611.0	[illegible]	[illegible]	[illegible]						
	200	673.5	39.12	86	7.824						

The operating power supply is 330mA and 3 LEDs are connected in parallel; therefore, the electrical current flown into each LED should be 110 mA.

input I_{FP} 110 mA | input I_{FP} mA

lm	VF	lm/W	W	lm/$	lm	VF	lm/W	W	lm/$
390.6	35.92	99	3.951						

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Figure 7. Example of Calculation (LED Down Light)

4.3. Preparation of LED Down Light

We prepared for a sample LED down light in accordance with the target specifications, using the LEDs with the following specifications:

LED Specifications

Part No.:	NFSL757D-V1
Quantity:	12 pcs. (4 series and 3 parallel)
Luminous Flux:	27.18lm(avg.) at 65mA applied to each LED
V_F:	2.93V(avg.) at 65mA applied to each LED
Color Rank:	sw27 (2,700K)
Color Rendering Rank:	R8000 (Ra>80)

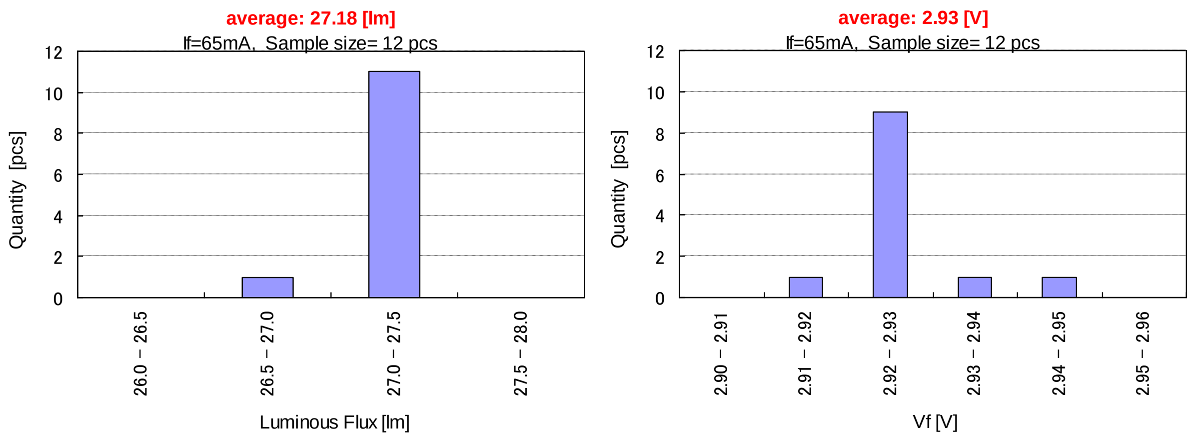

Figure 8. LED's Luminous Flux and V_F (12 LEDs)

5. Evaluation of LED Down Light Performance

5.1. Electrical/Optical Characteristics

Let us measure the electrical/optical characteristics of the LED down light prepared in Section 4.

Measurement Results of Sample LED Down Light

Power Consumption:	4.0W
Luminous Flux:	409lm
Efficiency:	101lm/W

5.2. Thermal Factor

The soldering temperature was measured with a thermocouple and the junction temperature was calculated.

Measurement Results of Sample LED Down Light

T_S (Soldering Temperature): 47.4°C

T_J (Junction Temperature): 47.4°C + 13°C/W × 0.32W = 51.6°C

where $R_{\Theta JS}$= 13°C/W * Specified for the LEDs

W= 2.9V × 110mA = 0.32W

5.3. Comparison between the Measured/Calculated Values

Let's compare the measured values and the calculated ones.

Table 6. Comparison of Measurement and Calculation

	Calculated	Measured	Difference
Tube Luminous Flux	391lm	409lm	+4.6%
Tube Efficiency	99lm/W	101lm/W	+2.0%

There was a slight difference between the measured and the calculated values.
Therefore, the measurement conditions should be reviewed and the measurement results should be evaluated again.
The LED junction temperature was 51.6°C, based on the measurement results. According to the LED specifications (cf. Section 4.3), the luminous flux and the V_F were 27.18lm and 2.93V per LED, respectively. Therefore, the measurement parameters were corrected as follows:

Table 7. Parameters and Measurement Values

	Before Corrected	After Corrected
Electrical current applied to each LED	110mA	110mA
Junction Temperature	50.0°C	51.6°C
Optical Loss	19.3%	19.3%
Electrical Loss	0%	0%
Qty of LEDs	12pcs.	12pcs.
Luminous Flux per LED	25.9lm (Typ.)	27.18lm
V_F per LED	2.90V (Typ.)	2.93V

Series	Series_757D_V1		
Type	NFSL757D_V1_R8000		
Spec Current (mA)	65		
Tj Max (degreeC)	120		
Luminous Flux (lm)	Min.	Typ.	Max.
	18.0	25.9	30.3
Forward Voltage V_F (V)	2.40	2.90	3.30

Color Rank	sw27	
Junction Temperatuer Tj (degreeC)	51.6	
Cost per LED		$
Optical Efficiency Loss (%)	19.3	
Electrical Efficiency Loss (%)		
LED Multiple	12	
Total Cost	0.000	$

Forward Current I_{FP}(mA)		lm	VF	lm/W	W	lm/$
input	200mA Max.	27.18	2.93	-	-	-
	10	40.4	31.53	128	0.315	
	15	60.7	31.91	127	0.479	
	20	80.9	32.26	125	0.645	
	30	121.0	32.88	123	0.987	
	40	160.3	33.43	120	1.337	
	50	198.7	33.91	117	1.696	
	65	254.3	34.56	113	2.247	
	75	290.1	34.96	111	2.622	
	80	307.6	35.16	109	2.813	
	100	375.7	35.92	105	3.592	
	120	441.8	36.67	100	4.400	
	150	540.2	37.80	95	5.670	
	180	639.7	38.89	91	7.001	
	200	705.2	39.58	89	7.916	

input I_{FP} 110 mA

lm	VF	lm/W	W	lm/$
408.9	36.29	102	3.992	

Info

Figure 9. Re-Calculation of LED Down Light

Let us compare the recalculation results and the measurement ones.

Table 8 Comparison of Recalculation Results and Measurement Results

	Calculated	Measured	Difference
Tube Luminous Flux	409lm	409lm	0%
Tube Efficiency	102lm/W	101lm/W	-1.0%

There was no difference in the lamp luminous flux between the recalculated and the measured values. The difference in the lamp efficiency became much smaller; therefore, the LED down light was designed in accordance with the calculation.

6. Summary

Design validation is critical when LEDs are installed into lighting fixtures. The performance should be validated by comparison between the calculated/measured values.
There is no significant difference between the measured / calculated values on this simulation, as long as the simulation is used for LEDs mounted on the board; however, you may not obtain the expected values for the lighting fixture due to optical/electrical loss resulting from the component materials and/or the fixture's structure.
In such cases, re-measure the performance after changing the parameters of the optical/electrical loss.
If it is difficult to measure the performance, such as the luminous flux and the V_F, because of the fixture's structure, it should be calculated and measured for the LEDs mounted on the board.

In this document, we used the typical thermal resistance $R_{\Theta JS}$ described by the specifications to calculate the LEDs' junction temperature; however, the characteristics vary when LEDs are installed in lighting fixtures.
As LEDs' junction temperature increases, in general, the light output reduces. Therefore, it is necessary to set the target luminous flux to ensure that the expected value is obtained even at the maximum thermal resistance.
Moreover, the forward voltage and the luminous flux vary even within the same rank. Therefore, assuming that the LEDs' characteristics are distributed at the minimum/maximum within the same rank, you should design lighting fixtures that ensure the expected values are within the specifications.

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