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Lighting Heat Gain Parameters: 
Experimental Results (RP-1282)

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The ASHRAE cooling load procedures employ a simple lighting heat gain model to account for the energy dissipated by lights. The simple lighting heat gain model requires knowledge of the conditioned space/ceiling plenum split in order to estimate how much of the lighting energy is transmitted to the conditioned space as heat gain. The model also requires the radiative/convective split in order to estimate how much of the lighting heat gain in the conditioned space is transferred as radiation and as convection. Experimental measurements of the lighting heat gain parameters were conducted for a range of contemporary luminaires in a full-scale test facility under realistic operating conditions. This paper presents experimental results along with their estimated uncertainties. The paper also discusses effects of various test parameters on the measured data. It is found that the lighting heat gain parameters are typically more sensitive to the luminaire type and the room airflow rate than to other parameters. Using different luminaires can result in an increase of 0.20 for the space fraction, which is higher than the typical uncertainty in the space fraction. Similarly, doubling the airflow rate can cause an increase of as much as 0.30 in the space fraction. On the other hand, other test parameters typically cause changes in the lighting heat gain parameters that are smaller than experimental uncertainties. This paper presents design data and application guidelines based on these findings. A companion paper discusses in detail the experimental method used to determine the lighting heat gain parameters.

INTRODUCTION

A number of experimental and numerical studies (Ball 1983a, 1983b; Chung and Loveday 1998a, 1998b; Kimura and Stephenson 1968; Mitalas and Kimura 1971; Mitalas 1973a, 1973b; Nevins et al. 1971; Nottage and Park 1969; Rundquist 1990; Sowell and O’Brien 1973; Sowell 1990, 1993; Treado and Bean 1990, 1992) have investigated lighting system performance and the influence of the lighting system on the cooling load. Most of these studies were done when the transfer function (TF) method was the method of choice for cooling load calculation. Therefore, information regarding the room transfer function coefficients (or weighting factors) are typically presented in the literature for estimating the cooling load caused by lights (Ball 1983a, 1983b; Mitalas 1973a, 1973b; Rundquist 1990; Treado and Bean 1992). Recently, ASHRAE developed two new cooling load calculation procedures: the heat balance (HB) and the radiant time series (RTS) methods (Pedersen et al. 1998). The two new methods take different approaches from the TF method in handling how the lighting energy becomes cooling load. In
the TF method, a set of room transfer function coefficients is used in estimating the cooling load caused by lights. Each set of room transfer function coefficients represents a combined effect of various parameters, including room constructions and the lighting system, and thus is only applicable for a particular combination. On the other hand, both the HB and the RTS methods improve upon the TF method by considering the lighting energy dissipated as radiation and as convection separately. Consequently, the room constructions and the lighting system are treated as separate entities, meaning that lighting heat gain parameters for a particular luminaire measured in a full-scale test room can be applied to a range of room constructions.

To account for heat gains due to lights, both the HB and the RTS methods use a simple lighting heat gain model. The model requires two lighting heat gain parameters as inputs: the conditioned space/ceiling plenum split and the radiative/convective split. The conditioned space/ceiling plenum split is used to estimate how much the lighting energy is transmitted to the conditioned space as heat gain. The conditioned space/ceiling plenum split is only necessary for in-ceiling luminaires since it can be assumed that the heat generated by non-in-ceiling luminaires is all dissipated in the conditioned space. On the other hand, the radiative/convective split used to estimate how much of the lighting heat gain in the conditioned space is transferred as radiation and as convection is essential for both in-ceiling and non-in-ceiling luminaires. Existing data of these two lighting heat gain parameters are very limited. The 2005 ASHRAE Handbook—Fundamentals (ASHRAE 2005) only reports the radiative/convective split. Presently, only Sowell and O’Brien (1973) present enough information to estimate both the conditioned space/ceiling plenum split and the radiative/convective split. However, they only present data for a fluorescent luminaire with an acrylic lens. As shown in the companion paper, measurement results presented in this paper for a similar fixture agree with the Sowell and O’Brien data within the range of experimental uncertainty. In addition, this paper presents lighting parameters for eight other commonly used light fixtures.

In order to provide HVAC designers current and usable information, experimental measurements of lighting heat gain parameters were conducted for a range of common luminaires in a full-scale test facility under realistic operating conditions. The experimental facility and methodology are discussed in detail in the companion paper (Chantrasrisalai and Fisher 2007). The lighting heat gain of the conditioned space is determined by performing heat balance calculations. The conditioned space fraction is then defined as the ratio of the conditioned space lighting heat gain to the electrical power consumed by the lighting system. The ceiling plenum fraction can then simply be determined as one minus the conditioned space fraction. The net radiant heat gains are determined by summing the product of the measured net radiant fluxes and their associated area. The radiative fractions (both shortwave and longwave) are then defined as the ratios of net radiant heat gains to the lighting electrical power use. Finally, the convective fraction can simply be determined as the difference between the conditioned space fraction and the sum of the radiative fractions.

The definition of the radiative and convective fractions presented in the “Experimental Results and Discussion” section of this paper differs from the conventional definition of the radiative/convective split (ASHRAE 2005) presented in the “Design Data and Application Guidelines” section of this paper. In the experimental results section, the radiative/convective split is based on the lighting power input and is typically less than one for an in-ceiling luminaire and equal to one for a non-in-ceiling luminaire. In the design data section, the radiative/convective split is based on the lighting heat gain of the conditioned space and is always equal to one. The alternate definition of the radiative/convective split presented in the experimental results section is included because it provides better insight into the physics of lighting energy distribution than does the conventional definition. The data are also included in conven-
tional format to facilitate application of the experimental results to cooling load and energy calculation procedures.

EXPERIMENTAL TESTS

A range of contemporary luminaires commonly used in commercial buildings was tested. They are listed in Table 1. The experimental configuration (as shown in Figure 2 in the companion paper [Chantrasrisalai and Fisher 2007]) and the test room operating conditions are as follows for all base experimental tests:

- The raised floor of the test room is carpeted.
- The conditioned air is supplied through the radial ceiling diffuser.
- The return air is configured for the ceiling plenum return (i.e., nonducted return).
- The airflow rate per floor area is approximately 1.0 cfm/ft² (5.1 L/s·m²).
- The average supply air temperature at the supply air diffuser is maintained between 59.0°F and 62.0°F (15.0°C and 16.7°C).
- The average room air temperature is maintained between 72.0°F and 75.0°F (22.2°C and 23.9°C).

In addition to the basic set of experiments, several tests were also performed to investigate the effect of various parameters, including airflow rate, return air configuration, floor finish, and supply and room air temperatures.

EXPERIMENTAL RESULTS AND DISCUSSION

This section presents experimental results, including the special allowance factor, the conditioned space/ceiling plenum split, and the radiative/convective split. In the following sections, effects of luminaire type, airflow rate, return air configuration, floor finish, and air temperatures on the conditioned space/ceiling plenum split and the radiative/convective split are discussed in detail. General observations from the analysis are summarized as follows:

- The actual power consumption was less than the rated power input of the fluorescent lamps for all tests with T-8 fluorescent luminaires. On the other hand, the actual power consumption and the rated power input were about the same for all tests with other lamp types. The ratio of the actual power consumption to the rated power input, the so-called “special allowance factor,” varied slightly between 0.87 and 0.90 for tests with T-8 luminaires but between 0.98 and 1.02 for tests with other lamp types. Since the total uncertainty in the electrical power measurement is estimated to be ±0.25% of the measured power, the variation in the special allowance factor is more likely due to a combined effect of airflow rate and temperature rather than due to fluctuations in the measured line voltage. These results indicate that typical operating conditions used in the current study are close to rated operating conditions for all lamp types, except for the T-8 lamps.
- Changing room/system configurations and conditions appeared to have a trivial effect on the shortwave radiative fraction. Differences in the shortwave fraction due to changes for the same luminaire(s) were only about 0.02. On the other hand, using different luminaires might result in higher differences in the shortwave radiative fraction.
- Changing room/system configurations and conditions had more a significant effect on other fractions, including the conditioned space fraction, the longwave radiative fraction, and the convective fraction. Changing the airflow rate seemed to cause higher differences in these fractions than other changes did.
The luminaires listed in Table 1 were tested to investigate the effect of luminaire type on the lighting heat gain parameters. For these experiments, typical room/system configurations and typical room operating conditions as described in the previous section were used. Both recessed fluorescent luminaires and downlight luminaires were evaluated. The recessed fluorescent luminaires include luminaires #1 through #6, while the downlight luminaires include luminaires #7 through #9.

### Effect of Luminaire Type

The luminaires listed in Table 1 were tested to investigate the effect of luminaire type on the lighting heat gain parameters. For these experiments, typical room/system configurations and typical room operating conditions as described in the previous section were used. Both recessed fluorescent luminaires and downlight luminaires were evaluated. The recessed fluorescent luminaires include luminaires #1 through #6, while the downlight luminaires include luminaires #7 through #9.

#### Recessed Fluorescent Luminaires

The recessed fluorescent luminaires include parabolic luminaires (#1 and #3), acrylic lens luminaires (#2 and #4), a direct/indirect luminaire (#5), and a volumetric luminaire (#6). Table 2 numerically summarizes test results for the recessed fluorescent luminaires. Figure 1 graphically compares the test results, and Figure 2 illustrates the effect of the luminaire type on each lighting heat gain parameter. Each luminaire has quite distinct design features for various purposes, such as lighting distribution, glare prevention, and/or air handling. Figure 3 shows some essential features of the recessed fluorescent luminaires.
Table 2. Results for Tests with Recessed Fluorescent Luminaires

<table>
<thead>
<tr>
<th>Fixture No.</th>
<th>Luminaire Feature</th>
<th>Special Allowance Factor</th>
<th>Conditioned Space/Plenum Split</th>
<th>Radiative/Convective Split</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td></td>
<td></td>
<td>Space Fraction</td>
<td>PLenum Fraction</td>
</tr>
<tr>
<td>1</td>
<td>Recessed, parabolic louver, nonvented, T-8</td>
<td>0.89</td>
<td>0.69 ± 0.09</td>
<td>0.31 ± 0.09</td>
</tr>
<tr>
<td>2</td>
<td>Recessed, acrylic lens, nonvented, T-8</td>
<td>0.88</td>
<td>0.44 ± 0.09</td>
<td>0.56 ± 0.09</td>
</tr>
<tr>
<td>3</td>
<td>Recessed, parabolic louver, vented, T-8</td>
<td>0.88</td>
<td>0.72 ± 0.10</td>
<td>0.28 ± 0.10</td>
</tr>
<tr>
<td>4</td>
<td>Recessed, acrylic lens, vented, T-8</td>
<td>0.89</td>
<td>0.46 ± 0.08</td>
<td>0.54 ± 0.08</td>
</tr>
<tr>
<td>5</td>
<td>Recessed, direct/indirect, T-8</td>
<td>0.90</td>
<td>0.66 ± 0.10</td>
<td>0.34 ± 0.10</td>
</tr>
<tr>
<td>6</td>
<td>Recessed, volumetric, T-5</td>
<td>1.01</td>
<td>0.46 ± 0.13</td>
<td>0.54 ± 0.13</td>
</tr>
</tbody>
</table>

Figure 1. Test results for recessed fluorescent luminaires.
Figure 2. Effect of luminaire type for recessed fluorescent luminaires.

Figure 3: Essential design features of recessed fluorescent luminaires.
tures that have a noticeable effect on the lighting heat gain parameters include a lens, a side slot return, and shielding used to prevent direct glare.

The presence of the lens appeared to have the most significant effect on the conditioned space fraction for recessed fluorescent luminaires. As shown in Table 2, differences in the space fraction among luminaires without the lens (Fixtures #1, #3, and #5) were less than 0.07 and those among luminaires with the lens (Fixtures #2, #4, and #6) were less than 0.03. On the other hand, differences in the space fraction between luminaires without the lens and those with the lens were mostly more than 0.20, which was larger than typical uncertainties in the space fraction. As illustrated in Table 2 and Figure 2, the presence of the lens also noticeably reduced both the longwave radiative and the convective fractions but seemed to have a minimal effect on the shortwave radiative fraction.

The use of side-slot returns in place of a ceiling grille (#1 vs. #3 and #2 vs. #4) slightly increased the conditioned space fractions, but the increases were small compared to uncertainties in the space fraction. The increases were insignificant due to the fact that although the use of side-slot returns caused increases in the convective fraction, it also caused reductions in both shortwave and longwave radiative fractions (there was a small reduction in the shortwave fraction for parabolic luminaires, but the differences were insignificant).

Compared to the parabolic luminaire (#1), the direct/indirect luminaire (#5) slightly reduced the space fraction, but the reduction was small compared to uncertainties in the space fraction. Like the luminaires with side-slot returns, the direct/indirect luminaire caused a reduction in both shortwave and longwave radiative fractions but an increase in the convective fraction. Unlike the luminaires with side-slot returns, the direct/indirect luminaire caused a relatively large reduction in the radiative fractions, which more than offset the increase in the convective fraction and resulted in a reduction in the space fraction.

For recessed fluorescent luminaires, variation in the shortwave radiative fraction was small, while variations in the longwave radiative and the convective fractions were large. Since room operating conditions (both airflow rate and temperatures) were not controlled to the same exact conditions for all tests, the larger discrepancies in the longwave radiative and the convective fractions were expected due to the strong dependency of the longwave radiation and convection on airflow rate and temperature.

In general, the shortwave radiative fraction was about 0.20 for luminaires with either a lens or side-slot returns. The negligible differences in the shortwave fraction indicated that the lens or the side-slot returns alone had a trivial effect on the shortwave radiant heat gain. On the other hand, a combination of the lens and the side-slot returns caused a slight reduction in the shortwave radiative fraction. The most significant effect on the shortwave radiative fraction was caused by the glare shield used in the direct/indirect luminaire to partially block direct emission of the lighting energy into the space.

Distinct design features (for lighting distribution) in each particular luminaire appeared to have small effects on the shortwave radiative heat flux distribution, as shown in left-hand side plots of Figure 4, but had a more noticeable effect on the longwave radiative heat flux distribution, as shown in right-hand side plots of Figure 4. It should be noted that variations in both shortwave and longwave radiative heat flux distributions were caused by room conditions as well. As illustrated in Figure 4, the noticeably nonsymmetrical distributions along the x-axis, particularly for the longwave radiative heat flux, were likely caused by the supply air from the ceiling diffuser located near the far left corner of the luminaires (see Figure 4 in the companion paper [Chantrasrisalai and Fisher 2007]).

**Downlight Luminaires.** Downlight luminaires include a 6 in. (0.15 m) diameter compact fluorescent luminaire with horizontal lamps, an 8 in. (0.20 m) diameter compact fluorescent luminaire with vertical lamp, and a 6 in. (0.15 m) incandescent luminaire. Two lamp types were
Figure 4. Radiative heat flux distributions for recessed fluorescent luminaires.
tested in the incandescent luminaire—a standard bulb (A21) and a “bulged-reflector bulb” (BR40). Table 3 summarizes test results for the downlight luminaires. Figure 5 graphically compares the test results, and Figure 6 illustrates the effect of the luminaire type on each lighting heat gain parameter.

**Table 3. Results for Tests with Downlight Luminaires**

<table>
<thead>
<tr>
<th>Fixture No.</th>
<th>Luminaire Feature</th>
<th>Special Allowance Factor</th>
<th>Conditioned Space/Plenum Split</th>
<th>Radiative/Convective Split</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td></td>
<td></td>
<td>Space Fraction</td>
<td>Plenum Fraction</td>
</tr>
<tr>
<td>7</td>
<td>Downlights, compact fluorescent, DTT</td>
<td>1.02</td>
<td>0.14</td>
<td>0.86</td>
</tr>
<tr>
<td>8</td>
<td>Downlights, compact fluorescent, TRT</td>
<td>1.02</td>
<td>0.22</td>
<td>0.78</td>
</tr>
<tr>
<td>9A</td>
<td>Downlights, incandescent, A21</td>
<td>0.98</td>
<td>0.71</td>
<td>0.29</td>
</tr>
<tr>
<td>9B</td>
<td>Downlights, incandescent, BR40</td>
<td>0.98</td>
<td>0.79</td>
<td>0.21</td>
</tr>
</tbody>
</table>
For Fixtures #7, #8, and #9B, the space fraction was equal to the sum of the radiative fractions and the convective fraction was zero. Test results for these three fixtures reflect the fact that experimental uncertainties in the space fraction (and in the convective fraction) are high. The convective fraction for the remaining test (#9A) was also near zero, indicating that most of the lighting energy going into the conditioned space was in the form of radiation for all downlight luminaires. This is not an unreasonable result since for downlight luminaires all hot surfaces are above the plane of the ceiling. The ceiling jet does not impinge on these surfaces, leaving recirculating flow in the fixture cavity as the only possible mechanism for convective heat transfer to the room. The results indicate that air movement through the fixture to the plenum dominates the convective transport and that the recirculating effect is negligible.

For downlight luminaires, the lamp type (i.e., compact fluorescent vs. incandescent) appeared to have the most significant effect on the conditioned space fraction, while the sub-lamp type, which specifies the lamp configuration (e.g., “double twin-tube” compact fluorescent vs. “tri-tube” compact fluorescent) or bulb shape (e.g., “standard” incandescent vs. “reflector” incandescent), also had a noticeable effect on the space fraction. As shown in Table 3, changing the lamp configuration for compact fluorescent luminaires and changing the bulb shape for incandescent luminaires both resulted in a change in the space fraction of about 0.08. On the other hand, changing from a compact fluorescent luminaire to an incandescent luminaire resulted in a change in the space fraction of at least 0.49. The large difference in the space fraction between a compact fluorescent luminaire and an incandescent luminaire was primarily due to the shortwave radiative fraction. As shown, shortwave radiative fractions for compact fluorescent luminaires were between 0.10 and 0.13, whereas shortwave radiative fractions for incandescent luminaires were between 0.70 and 0.80.
descent luminaires varied between 0.60 and 0.71. These results indicated that most of the lighting energy was dissipated in the form of shortwave radiation for incandescent luminaires. As discussed in the companion paper, the measured shortwave spectrum includes, but is not limited to, the visible spectrum.

Fixture and reflector design features also seemed to have a significant effect on the lighting heat gain parameters for downlight compact fluorescent luminaires. Large holes in the reflector of the 6 in. (0.15 m) diameter luminaire with horizontal lamps (#7) not only facilitated convection to the plenum, as discussed in the preceding paragraph, but also resulted in significant radiative transport to the plenum. For a test with this luminaire, the ceiling plenum appeared to be as bright as the conditioned space, indicating that a significant fraction of the available visible radiation was lost to the plenum.

Effect of Airflow Rate

The effect of the room supply airflow rate was investigated for three luminaires: the parabolic luminaire (#1), the parabolic luminaire with side-slot returns (#3), and the direct/indirect luminaire (#5). For these experiments, only the airflow rate was changed; the room/system configurations and operating conditions were similar to those used for other tests. Table 4 summarizes test results for different room ventilative flow rates. Figure 7 graphically compares the test results and Figure 8 illustrates the effect of the airflow rate on each lighting heat gain parameter. As shown, differences in the conditioned space fraction for different luminaires with the same airflow rates were noticeably smaller than differences for the same luminaires with different airflow rates. These results illustrated a strong influence of the room airflow on the lighting heat gain to the conditioned space.

![Figure 6. Effect of luminaire type for downlight luminaires.](image-url)
Figure 7. Test results for different airflow rates.

Figure 8. Effect of airflow rate for recessed fluorescent luminaires without lens.
Increasing the room airflow rate caused an increase in the convective fraction, as expected. It also caused a reduction in both shortwave and longwave radiative fractions. The shortwave radiative fraction is less sensitive to the airflow rate than the longwave radiative fraction. Changing the airflow rate from 0.5 to 2.0 cfm/ft² (2.55 to 10.2 L/s·m²) resulted in a difference of 0.02 in the shortwave radiative fraction for all three luminaires tested. On the other hand, changing the airflow rate from 0.5 to 2.0 cfm/ft² (2.55 to 10.2 L/s·m²) could cause a reduction of as large as 0.14 in the longwave radiative fraction, as shown in Table 4. Since convection is quite sensitive to the airflow rate, changes in the convective fraction, as expected, were larger than changes in both the shortwave and the longwave radiative fractions, resulting in an increase in the space fraction with the increase in the airflow rate.

Table 4. Results for Tests with Different Airflow Rates

<table>
<thead>
<tr>
<th>Flow Rate, cfm/ft² (L/s·m²) of Floor Area</th>
<th>Fixture No.</th>
<th>Special Allowance Factor</th>
<th>Conditioned Space/Plenum Split</th>
<th>Radiative/Convective Split</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td></td>
<td></td>
<td>Space Fraction</td>
<td>Plenum Fraction</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>0.5 (2.55)</td>
<td>1</td>
<td>0.89</td>
<td>0.55 ±0.07</td>
<td>0.45 ±0.07</td>
</tr>
<tr>
<td></td>
<td>3</td>
<td>0.89</td>
<td>0.57 ±0.06</td>
<td>0.43 ±0.06</td>
</tr>
<tr>
<td></td>
<td>5</td>
<td>0.88</td>
<td>0.57 ±0.07</td>
<td>0.43 ±0.07</td>
</tr>
<tr>
<td>1.0 (5.1)</td>
<td>1</td>
<td>0.89</td>
<td>0.69 ±0.09</td>
<td>0.31 ±0.09</td>
</tr>
<tr>
<td></td>
<td>3</td>
<td>0.88</td>
<td>0.72 ±0.10</td>
<td>0.28 ±0.10</td>
</tr>
<tr>
<td></td>
<td>5</td>
<td>0.90</td>
<td>0.66 ±0.10</td>
<td>0.34 ±0.10</td>
</tr>
<tr>
<td>2.0 (10.2)</td>
<td>1</td>
<td>0.89</td>
<td>0.90 ±0.17</td>
<td>0.10 ±0.17</td>
</tr>
<tr>
<td></td>
<td>3</td>
<td>0.88</td>
<td>0.89 ±0.19</td>
<td>0.11 ±0.19</td>
</tr>
<tr>
<td></td>
<td>5</td>
<td>0.90</td>
<td>0.96 ±0.17</td>
<td>0.04 ±0.17</td>
</tr>
</tbody>
</table>

Effect of Ducted Returns

To investigate the effect of ducted returns, two additional tests were conducted for the parabolic and the direct/indirect luminaires (#1 and #5) with return air ducts in the ceiling plenum. Table 5 compares test results for ducted and nonducted plenum return air configurations. Changing the return air configuration from a nonducted return to a ducted return resulted in an increase in the conditioned space fraction for both luminaires tested. The increase in the space fraction (or the reduction in the plenum fraction) was due to the fact that the ceiling plenum with a ducted return was not ventilated, causing a reduction in the convective heat gain from the luminaires to the ceiling plenum. Nonetheless, changes in the space fraction due to changing the airflow rate from 0.5 to 2.0 cfm/ft² (2.55 to 10.2 L/s·m²) could cause a reduction of as large as 0.14 in the longwave radiative fraction, as shown in Table 4. Since convection is quite sensitive to the airflow rate, changes in the convective fraction, as expected, were larger than changes in both the shortwave and the longwave radiative fractions, resulting in an increase in the space fraction with the increase in the airflow rate.
return air configuration were smaller than changes in the space fraction due to changing the air-
flow rate. This suggests that the space fraction is more sensitive to the room airflow rate than to
the return air configuration.

Changing the return air configuration from a nonducted return to a ducted return caused an
increase in both shortwave and longwave radiative fractions for both luminaires. The reduced
convective transport through the fixtures to the plenum likely resulted in higher fixture and
bulb temperatures and consequently caused an increase in radiative transport to the room. The
convective fraction for the parabolic luminaire was slightly less for the ducted return than for
the nonducted return, whereas the convective fraction for the direct/indirect luminaire was
slightly greater for the ducted return. Although test results for the convective fraction are
inconsistent, changes in the convective fraction were much smaller than uncertainties in the
convective fraction and therefore may not be significant. As shown in Table 5, differences in
the convective fraction due to changing the return air configuration were smaller than differ-
ences in the longwave radiative fraction for both luminaires. These results indicate that the
longwave radiation to the room is more sensitive to the return air configuration than is the con-
vective heat transfer to the room.

Other Secondary Effects

Effect of Floor Finish. The effect of floor finish was investigated for three luminaires,
including the parabolic luminaire (#1), the parabolic luminaire with side-slot returns (#3), and
the direct/indirect luminaire (#5). The carpet was removed and the raised floor was covered with
linoleum tiles. Table 6 compares test results for the two floor finishes. As shown, the effect of
floor finish on the conditioned space fraction appeared inconsistent. Removing a carpet caused a
reduction in the space fraction for both parabolic luminaires but an increase for the direct/indi-
rect luminaire. The reduction was only 0.01 for the parabolic nonvented luminaire but about
0.07 for the parabolic vented luminaire. The higher difference for the parabolic vented luminaire
might be caused by the combined effect of the floor finish and the use of side-slot returns as well
as imperfect controls. However, these results are somewhat insignificant due to large uncertain-
ities in the space fraction. Compared to the uncertainty ranges, the changes due to removing the
carpet were quite small for all fractions, indicating that the lighting heat gain parameters were
not sensitive to the floor finish.

Table 5. Results for Tests with Different Return Air Configurations

<table>
<thead>
<tr>
<th>Return Air Configuration</th>
<th>Fixture No.</th>
<th>Special Allowance Factor</th>
<th>Conditioned Space/Plenum Split</th>
<th>Radiative/Convective Split</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td></td>
<td></td>
<td>Space Fraction</td>
<td>Plenum Fraction</td>
</tr>
<tr>
<td>Nonducted</td>
<td>1</td>
<td>0.89</td>
<td>0.69 ±0.09</td>
<td>0.31 ±0.09</td>
</tr>
<tr>
<td></td>
<td>5</td>
<td>0.90</td>
<td>0.66 ±0.10</td>
<td>0.34 ±0.10</td>
</tr>
<tr>
<td>Ducted</td>
<td>1</td>
<td>0.89</td>
<td>0.73 ±0.09</td>
<td>0.27 ±0.09</td>
</tr>
<tr>
<td></td>
<td>5</td>
<td>0.89</td>
<td>0.73 ±0.09</td>
<td>0.27 ±0.09</td>
</tr>
</tbody>
</table>


Effect of Air Temperatures. As discussed in previous sections, room operating conditions have not been controlled to the same exact conditions for all tests due to imperfect controls and some technical problems (e.g., the air-handling cooling coil was slightly undersized for tests with high loads; hence, the supply air temperature had to be raised slightly for tests with high airflow rate). A variation in the supply air temperature was less than 4°F (2.2°C) and a variation in the room air temperature was less than 3°F (1.7°C) for all experimental tests discussed earlier. In addition to other test parameters, it is also useful to investigate the effect of air temperatures on the lighting heat gain parameters.

Additional tests were conducted for the parabolic vented luminaire (#3) with no carpet configuration to investigate the effect of supply and room air temperatures. Table 7 summarizes experimental results along with varied supply air temperatures and relatively constant room air temperatures, whereas Table 8 summarizes experimental results along with relatively constant supply air temperatures and varied room air temperatures. As shown in Table 7, the longwave radiative fraction and the convective fraction are slightly sensitive to the supply air temperature. As expected, increasing the supply air temperature caused an increase in the longwave radiative fraction but a reduction in the convective fraction. Due to these opposite effects, changing the supply air temperature thus had a minimal effect on the space fraction.

As shown in Table 8, increasing the room air temperature caused a small but noticeable reduction in the longwave radiative fraction (i.e., small but not negligible compared to the uncertainty range). On the other hand, changing the room air temperature caused minimal changes in all other lighting heat gain parameters. Results presented in Tables 7 and 8 indicated that the longwave radiative and the convective fractions are slightly more sensitive to the supply air temperature than to the room air temperature.

### Table 6. Results for Tests with Different Floor Finishes

<table>
<thead>
<tr>
<th>Floor Finish</th>
<th>Fixture No.</th>
<th>Special Allowance Factor</th>
<th>Conditioned Space/Plenum Split</th>
<th>Radiative/Convective Split</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td></td>
<td></td>
<td>Space Fraction</td>
<td>Plenum Fraction</td>
</tr>
<tr>
<td></td>
<td>Carpet</td>
<td>1</td>
<td>0.69 ±0.09</td>
<td>0.31 ±0.09</td>
</tr>
<tr>
<td></td>
<td></td>
<td>3</td>
<td>0.72 ±0.10</td>
<td>0.28 ±0.10</td>
</tr>
<tr>
<td></td>
<td></td>
<td>5</td>
<td>0.66 ±0.10</td>
<td>0.34 ±0.10</td>
</tr>
<tr>
<td></td>
<td>No Carpet</td>
<td>1</td>
<td>0.68 ±0.09</td>
<td>0.32 ±0.09</td>
</tr>
<tr>
<td></td>
<td></td>
<td>3</td>
<td>0.65 ±0.09</td>
<td>0.35 ±0.09</td>
</tr>
<tr>
<td></td>
<td></td>
<td>5</td>
<td>0.68 ±0.10</td>
<td>0.32 ±0.10</td>
</tr>
</tbody>
</table>

As expected, increasing the supply air temperature caused an increase in the longwave radiative fraction but a reduction in the convective fraction. Due to these opposite effects, changing the supply air temperature thus had a minimal effect on the space fraction.

As shown in Table 8, increasing the room air temperature caused a small but noticeable reduction in the longwave radiative fraction (i.e., small but not negligible compared to the uncertainty range). On the other hand, changing the room air temperature caused minimal changes in all other lighting heat gain parameters. Results presented in Tables 7 and 8 indicated that the longwave radiative and the convective fractions are slightly more sensitive to the supply air temperature than to the room air temperature.

**DESIGN DATA AND APPLICATION GUIDELINES**

As shown by the numerical analysis presented in the companion paper, the lighting heat gain parameters are relatively constant even during periods of transient cooling loads. The estimated
effect of transient room conditions is well within the range of experimental uncertainty and sug-
gests that the use of constant lighting heat gain parameters determined under steady-state condi-
tions is reasonably accurate.

The nine luminaires for which data are presented may be categorized into four groups: the
recessed fluorescent luminaire without a lens, the recessed fluorescent luminaire with a lens, the
downlight compact fluorescent luminaire, and the downlight incandescent luminaire. Table 9
provides a range of design data for the conditioned space fraction, the shortwave radiative frac-
tion, and the longwave radiative fraction for the four luminaire categories under typical operat-

<table>
<thead>
<tr>
<th>Supply Air Temperature, °F (°C)</th>
<th>Room Air Temperature, °F (°C)</th>
<th>Special Allowance Factor</th>
<th>Conditioned Space/Plenum Split</th>
<th>Radiative/Convective Split</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td></td>
<td></td>
<td>Space Fraction</td>
<td>Plenum Fraction</td>
</tr>
<tr>
<td>61.1 (16.2)</td>
<td>73.3 (22.9)</td>
<td>0.88</td>
<td>0.65 ±0.09</td>
<td>0.35 ±0.09</td>
</tr>
<tr>
<td>65.2 (18.4)</td>
<td>72.9 (22.7)</td>
<td>0.88</td>
<td>0.65 ±0.08</td>
<td>0.35 ±0.08</td>
</tr>
<tr>
<td>70.4 (21.3)</td>
<td>72.6 (22.6)</td>
<td>0.88</td>
<td>0.63 ±0.08</td>
<td>0.37 ±0.08</td>
</tr>
</tbody>
</table>

Table 8. Results for Tests with Different Room Air Temperatures

<table>
<thead>
<tr>
<th>Supply Air Temperature, °F (°C)</th>
<th>Room Air Temperature, °F (°C)</th>
<th>Special Allowance Factor</th>
<th>Conditioned Space/Plenum Split</th>
<th>Radiative/Convective Split</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td></td>
<td></td>
<td>Space Fraction</td>
<td>Plenum Fraction</td>
</tr>
<tr>
<td>65.0 (18.3)</td>
<td>68.0 (20.0)</td>
<td>0.87</td>
<td>0.65 ±0.08</td>
<td>0.35 ±0.08</td>
</tr>
<tr>
<td>65.2 (18.4)</td>
<td>72.9 (22.7)</td>
<td>0.88</td>
<td>0.65 ±0.08</td>
<td>0.35 ±0.08</td>
</tr>
<tr>
<td>65.2 (18.5)</td>
<td>76.6 (24.8)</td>
<td>0.89</td>
<td>0.62 ±0.09</td>
<td>0.38 ±0.09</td>
</tr>
</tbody>
</table>

ing conditions (airflow rate of 1 cfm/ft² [5.1 L/s·m²], supply air temperature between 59°F and
62°F [15.0°C and 16.7°C], and room air temperature between 72°F and 75°F [22.2°C and
23.9°C]). If needed, the plenum fraction can simply be determined as one minus the conditioned
space fraction, and the convective fraction can simply be determined as one minus the sum of
the radiative fractions. Typically, using values in the middle of the range will yield sufficiently
accurate results. However, values may be adjusted slightly according to notes given in Table 9
to better reflect a specific situation. As previously noted, the design data provided in Table 9 for
the radiative fractions are based on the conventional definition of the radiative/convective split.

In the companion paper, a numerical analysis based on a detailed lighting model (Sowell and
O’Brien 1973; Sowell 1990) for the recessed fluorescent luminaire with acrylic lens shows that
the lighting heat gain parameters are somewhat sensitive to luminaire-related parameters, partic-

ularly the lighting power input. Doubling the room total lighting power input causes quite a significant reduction in both the space and the shortwave fractions, but a trivial increase in both the longwave and convective fractions. For experimental tests in the current study, the total lighting power input per floor area ranged from 0.9 to 2.6 W/ft² (9.7 to 28.0 W/m²). If the design power input per floor area is within the range of the experimental measurements, recommendations given in Table 9 should be sufficiently accurate. For design power input higher than 2.6 W/ft² (28.0 W/m²), the lower bounds of the space and shortwave fractions should be used, and for design power input less than 0.9 W/ft² (9.7 W/m²), the upper bounds of the space and shortwave fractions should be used.

### Table 9. Lighting Heat Gain Parameters for Typical Operating Conditions

<table>
<thead>
<tr>
<th>Luminaire Category</th>
<th>Space Fraction</th>
<th>SW Radiative Fraction</th>
<th>LW Radiative Fraction</th>
<th>Notes</th>
</tr>
</thead>
</table>
| Recessed fluorescent luminaire without lens | 0.64–0.74 | 0.23–0.31 | 0.25–0.37 | • Use middle values in most situations.  
• May use higher space fraction and lower radiative fractions for luminaire with side-slot returns.  
• May use lower values for all fractions for direct/indirect luminaire.  
• May use higher values for space and longwave radiative fractions for ducted returns |
| Recessed fluorescent luminaire with lens | 0.40–0.50 | 0.39–0.45 | 0.22–0.28 | • May adjust values similar to those noted for recessed fluorescent luminaire without lens |
| Downlight compact fluorescent luminaire | 0.12–0.24 | 0.60–0.70 | 0.30–0.40 | • Use middle or high values if detailed features are unknown.  
• Use low values for space and longwave radiative fractions and high value for shortwave radiative fraction if there are large holes in the reflector of the luminaire. |
| Downlight incandescent luminaire | 0.70–0.80 | 0.85–0.90 | 0.10–0.15 | • Use middle values if lamp type is unknown.  
• Use low values for space and shortwave radiative fractions and high value for longwave radiative fraction if a standard lamp (i.e., A-lamp) is used.  
• Use high values for space and shortwave radiative fractions and low value for longwave radiative fraction if a reflector lamp (i.e., BR-lamp) is used. |
If the room airflow rate is different from typical conditions (i.e., about 1 cfm/ft² [5.1 L/s·m²]), Figure 9 can be used to estimate the lighting heat gain parameters. The figure shows recommended design lighting heat gain parameters (i.e., middle values) along with their design upper and lower bounds. Using values within the bounds should yield sufficiently accurate results. Design data shown in Figure 9 are only applicable for the recessed fluorescent luminaire without lens. The results of the sensitivity study using a detailed lighting program presented in the companion paper (Chantrasrisalai and Fisher 2007) showed the opposite trend for a recessed fluorescent luminaire with an acrylic lens.

Although design data presented in Table 9 and Figure 9 can be used for a vented luminaire with side-slot returns, they are likely not applicable for a vented luminaire with lamp-compartment returns since all heat convected in the vented luminaire with lamp-compartment returns would likely go directly to the ceiling plenum, resulting in (zero convective fraction and) a much lower space fraction than that for a vented luminaire with side-slot returns. Therefore, the design data should only be used for a configuration where the conditioned air is returned through the ceiling grille or the luminaire side slots.

Although the data are applicable for both ducted and nonducted returns, the application of the data, particularly the ceiling plenum fraction, may vary for different return configurations. For instance, for a room with a ducted return, although a portion of the lighting energy initially dissipated to the ceiling plenum is quantitatively equal to the plenum fraction, a large portion of this energy would likely end up as the conditioned space cooling load and a small portion would end up as the cooling load to the return air. This means that the ceiling plenum lighting heat gain should not be added directly to the cooling coil load as a cooling load due to return air. A better application of design data for a room with a ducted return would be to model not only the conditioned space but also the ceiling plenum to account for a delay due to thermal storage in the ple-

![Figure 9. Lighting heat gain parameters for recessed fluorescent luminaire without lens.](image-url)
num and building constructions. On the other hand, for a room with a nonducted return, adding the ceiling plenum lighting heat gain as the cooling load due to return air is reasonably valid if only the conditioned space is modeled.

As discussed in the companion paper (Chantarrisalai and Fisher 2007), the pyranometers used for shortwave radiation measure radiant heat fluxes in the solar spectrum (0.3–2.8 µm), which include the whole visible spectrum and a portion of the ultraviolet and the (near) infrared spectrums. On the other hand, the pyrgeometers used for longwave radiation measure radiant heat fluxes in the far infrared spectrum (5–50 µm). Essentially, the terms shortwave and long-wave may thus be used interchangeably with the terms solar and far infrared, respectively. Since the solar absorbance and the longwave emittance of the same surface can be quite different, the shortwave and the longwave radiative fractions should be used separately to better reflect actual radiation interchanges in the room. This recommendation is, however, only applicable for the HB method since the RTS method inherently does not differentiate between shortwave and longwave radiative distributions (i.e., nonsolar radiant time factors are used for both shortwave and longwave heat gains due to lights).

It is interesting to discuss one special case for the RTS method. For downlight luminaires, a large portion of the shortwave radiation typically falls on the floor (radiative distributions of the downlight luminaires are more directional than radiative distributions of the recessed fluorescent luminaires). Therefore, for the downlight luminaires, using the solar radiant time factors for the total radiative heat gain due to lights may be more appropriate than using nonsolar radiant time factors. A significant difference due to using the solar radiant time factors will occur when the solar radiant time factors are quite different from the nonsolar radiant time factors and the total radiative heat gain is high. An example of this particular case is when the downlight incandescent luminaires (which have very high radiative fractions, particularly the shortwave fraction, as shown in Table 3) are used in a room with lightweight walls and a heavyweight floor. For this application, the solar radiant time factors should be applied to the radiative lighting heat gain.

CONCLUSIONS

Experimental measurements of lighting heat gain parameters, the conditioned space/ceiling plenum split and the radiative/convective split, were conducted in a full-scale test facility under realistic operating conditions. Various test parameters were investigated to determine their influence on the lighting heat gain parameters. These parameters included luminaire type, room airflow rate, return air configuration, floor finish, as well as air temperatures. It is found that the lighting heat gain parameters are typically more sensitive to the luminaire type and the room airflow rate than to other test parameters.

Based on the luminaires tested, the presence of a lens appeared to have the most significant effect on the conditioned space/ceiling plenum split for recessed fluorescent luminaires. The presence of a lens reduced the conditioned space fraction by at least 0.20, the longwave radiative fraction by at least 0.04, and the convective fractions by at least 0.09. However, the presence of the lens seemed to have no noticeable effect on the shortwave radiative fraction. For downlight luminaires, all lighting heat gain parameters except the convective fraction were largely dependent on the lamp type. For all downlight luminaires tested, the radiant energy constituted most of the lighting energy going into the conditioned space (i.e., the convective heat gain was zero or near zero). The space fraction varied between 0.14 and 0.22 for the downlight compact fluorescent luminaires, while the space fraction varied between 0.71 and 0.79 for the downlight incandescent luminaires. For luminaires tested (recessed fluorescent without a lens), doubling the airflow rate caused increases in the space fraction between 0.09 and 0.30, reductions in the longwave radiative fractions between 0.04 and 0.08, and increases in the convective fraction between 0.21 and 0.34. On the other hand, for the shortwave radiative fraction, quadrupling the airflow rate only resulted in reductions of 0.02 for all luminaires tested.
Based on experimental findings, design ranges of the lighting heat gain parameters for typical operating conditions are presented for each of four groups of luminaires: the recessed fluorescent luminaire without a lens, the recessed fluorescent luminaire with a lens, the downlight compact fluorescent luminaire, and the downlight incandescent luminaire. In typical situations, using values in the middle of the range are expected to yield sufficiently accurate results. Recommendations for off-design conditions are also provided. Since the lighting heat gain parameters are sensitive to the airflow rate, design data given as a function of the airflow rate are also presented. However, the data are only applicable to the recessed fluorescent luminaire without a lens since other luminaire types have not been tested for different airflow rates.

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REFERENCES


