SUMMARY
There is now substantial evidence that exposure to blue-rich light in the evening and at night increases the risk of obesity and diabetes. Most energy efficient LEDs in the market today are rich in the blue wavelengths that at night trigger the metabolic processes involved in obesity and diabetes through:

1) Disruption of the circadian system (phase shifting and circadian misalignment),
2) Melatonin-suppression and phase shifting.

Blue-rich light (including natural daylight) during the day is protective, but exposure to the same blue rich LED or fluorescent light during the night is harmful. To avoid this risk light fixtures need to provide blue-rich light during the day, and blue-depleted light at night.

This paper presents the scientific evidence and the lighting solutions now available.

Blue Light at Night Causal Chain: Obesity and Diabetes

Figure 1: Pathways mediating the effects of blue-rich light at night on obesity and diabetes
OVERVIEW OF SCIENTIFIC EVIDENCE

Based on 15 years of published peer-reviewed scientific research the evidence is powerful and convincing and has come from multiple corroborating sources:

- Obesity increased 43% and diabetes increased 37% in people regularly exposed to light at night while working night shifts based on 28 independent published studies.
- Obesity increased 96% in non-shiftworking people sleeping in bedrooms with the lights on at night.
- Increasing levels of environmental light pollution associated with increased obesity.
- Animal studies showing obesity and diabetes are increased by exposure to light at night, and the effect involves the circadian disruption of insulin-producing pancreatic beta cells.
- Healthy human volunteers exposed to blue-rich light at night have disrupted circadian rhythms, suppressed melatonin, increase appetite, and increased insulin resistance and glucose intolerance, and the effects are independent of sleep loss.
- Removal of blue wavelengths from white light at night, while maintaining the same light intensity, reverses the increased appetite and the insulin resistance caused by blue-rich LED lights at night.

This scientific research is summarized below with references to key articles in the peer-reviewed scientific literature.

<table>
<thead>
<tr>
<th>Authors</th>
<th>Date</th>
<th>Population</th>
<th>Odds Ratio</th>
<th>Increased Risk</th>
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</thead>
<tbody>
<tr>
<td>Sun</td>
<td>1999</td>
<td>Meta-analysis of 28 studies on obesity &amp; permanent night workers</td>
<td>1.43</td>
<td>+ 43%</td>
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<tr>
<td>McFadden</td>
<td>2014</td>
<td>Obesity in women sleeping in bedrooms with increased light levels</td>
<td>1.96</td>
<td>+ 96%</td>
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<tr>
<td>Gan</td>
<td>2015</td>
<td>Diabetes in men working nights (Meta analysis of 28 independent studies)</td>
<td>1.37</td>
<td>+ 37%</td>
</tr>
<tr>
<td>Hansen</td>
<td>2016</td>
<td>Diabetes new cases developing in female nurses working nights</td>
<td>1.58</td>
<td>+ 58%</td>
</tr>
</tbody>
</table>

Figure 2: The increased risk of obesity and diabetes in people exposed to light at night

Night Shift Work and Obesity

The population exposed to the highest levels light exposure at night and circadian disruption are people who work night shifts. Sun et al. [1] conducted a recent meta-analysis of 28 independent published studies of the association between shift work and obesity and showed the overall odds ratio for the risk of obesity/overweight with night shift work was 1.23 (95% confidence interval = 1.17–1.29). In particular, shift workers had a higher frequency of developing abdominal obesity (odds ratio = 1.35) than other obesity types. Permanent night workers demonstrated a 29% higher risk than rotating shift workers (odds ratio 1.43 vs. 1.14).

This relationship between night shift work and obesity and metabolic syndrome is supported by multiple other review studies [2,3,4] and cohort studies [5,6,7,8].
Bedroom Light at Night and Obesity

The effects of increased levels of light exposure at night are also seen in non-shiftworkers who sleep at home at night. In a study of 113,000 United Kingdom women, BMI, waist-hip ratio and waist height ratio, and waist circumference increased with increased light levels in the room they slept in at night [9]. These associations were still present after adjustment for age, socioeconomic status, alcohol consumption, strenuous physical activity, night-shift work, having a young child, sleep duration, and current smoking. Exposure to LAN was assessed through participants' answers to a categorical-response question about the lightness of the room they slept in; the response categories were “light enough to read”; “light enough to see across the room, but not read”; “light enough to see your hand in front of you, but not to see across the room”; and “too dark to see your hand, or you wear a mask.”

Similarly, a cross-sectional study of 500 people in Japan [10] found that elderly people sleeping in lighter bedrooms had higher body weight, waist circumference, and BMI; which were all objectively measured.

In keeping with this evidence, there is an association between the patterns of increasing environmental light levels at night and increasing obesity rates across the United States over the last several decades [11] (Figure 5.1).

The relationship between light exposure at night and obesity has also been demonstrated in animal studies which show that nocturnal light exposure causes weight gain, even when calorie intake and physical activity are held constant [12].

Night Shift Work and Diabetes

Multiple literature reviews, meta-analyses and cohort studies on workers who regularly work night shifts over many years, show that night work and rotating shift-work are linked to an increased incidence of type 2 (adult onset) diabetes mellitus and related conditions such as obesity and metabolic syndrome.

A meta-analysis of twelve studies (including 28 independent reports) [13] concluded that shift work is associated with an increased risk of diabetes, especially in men subjected to light at night and circadian disruption associated with rotating work schedules. The analysis involved over 226,000 participants and showed on average an 37% increased diabetes risk in men.
In women the positive association between night shift work and diabetes has been demonstrated in several cohort studies:

- Data from two large prospective cohort studies (Nurses’ Health Studies I and II) following a total of over 170,000 nurses without diabetes at baseline for 18-20 years [14] suggested that extended exposure to rotating night work is associated with a modestly increased risk of type 2 diabetes in women. The study concluded that the increased diabetes risk was partly mediated through body weight.

- The Danish Cohort Study [15] followed nearly 20,000 female nurses who were diabetes-free at recruitment for 15 years. Nurses who worked night or evening shifts had an increased risk for diabetes, with night shifts posing the highest risk.

- Similarly, initial data from the ongoing Black Women’s Health Study show an increased diabetes risk with long-term night work [16].

### Mechanisms of Action

Studies using animal models and controlled laboratory studies with human subjects have identified the mechanisms of action on the causal pathway between blue-rich light exposure and obesity, metabolic syndrome and diabetes. Most white LED and fluorescent lights in the market have significant blue content. The blue (430-500nm) irradiance falls on retinal ganglion cells in the eye which are highly sensitive to blue wavelengths. At normal room lighting levels (200-500 lux) at night this causes disruptions in the timing of the circadian clock and suppresses melatonin, both of which have adverse effects on appetite, obesity, insulin resistance and diabetes risk.

### Light Exposure and Disorders of Glucose Metabolism

Exposure to light at night has well documented effects on metabolic functions including decreased glucose tolerance and increased insulin resistance in animals [17,18] and humans [19].

Albreiki et al. [19] found significantly higher post-meal levels of glucose and insulin during a single-night with 500 lux white light exposure (as compared to 5 lux dim light), suggesting glucose intolerance and insulin insensitivity. Gil-Lozano et al [38] showed this is not due to sleep loss as people kept awake at night and exposed to light show insulin resistance, but not those kept awake in the dark.

Similarly, Cheung et al. [20] showed that exposure to blue-enriched light (peaking at 468nm) in the morning and evening can alter glucose metabolism, with a relative increase in insulin resistance with blue-enriched light exposure compared to dim light exposure.
Circadian Disruption

Sleep deprivation at night has been associated with glucose intolerance and diabetes [21], but in many of the early studies since the subjects were awake at night in a lighted room, they did not distinguish between the effects of the light exposure and versus sleep loss. More recently several studies have shown that light exposure at night increases insulin resistance and diabetic risk independent of sleep loss [38] and the effect is due to circadian disruption (or “circadian misalignment”) [22]. Morris et al. [23] showed that glucose levels were elevated in people whose circadian systems were disrupted as a result of decreased insulin sensitivity.

Blue-rich LED light exposure during 12-hour night shifts at 500 lux, which causes multi-hour circadian phase shifts, progressively increases appetite during the night shift and insulin resistance after breakfast meal so by the second night shift post-breakfast insulin levels are double those after a baseline night of sleep [24].

The circadian disruption and the appetite and insulin resistance effects of blue rich LED light at night can be reversed using LED lights depleted of 430-500nm blue light.

These mechanisms of circadian disruption by light are seen at the cellular level in the pancreatic beta islet cells that synthesis and release insulin. Qian [25] showed that when the circadian system was disrupted in animals by constant light exposure, the circadian rhythms of pancreatic islet cell function were disrupted causing diminished glucose-stimulated insulin release.

Melatonin Suppression

Several studies have implicated a link between the nocturnal suppression of melatonin and the incidence of diabetes incidence [26] or diabetes-relevant impairments such as increased insulin resistance [27,28,29]. Melatonin has been implicated as a key factor for the synthesis, secretion and action of insulin, and for regulation of the expression of transporter glucose type 4 or triggering phosphorylation of the insulin receptor Ulhôa et al. [27]. A reduction in melatonin is associated with an increase in insulin resistance and a propensity for development of diabetes. Melatonin receptors are expressed in pancreatic islets, and melatonin appears to have an inhibitory action on insulin release [30,31,32].

**Figure 5:** Conventional Blue-Rich LEDs Double Insulin Resistance after only Two Night Shifts

**Figure 6:** Relationship between Melatonin Suppression and Diabetes Risk
Data from the Nurses’ Health Study [26] linked low nocturnal melatonin secretion to increased type 2 diabetes incidence. In a separate report [28] it was shown that lower nocturnal melatonin was also associated with higher insulin resistance. Similarly, a study on evening light exposure at home in elderly individuals demonstrated that evening light exposure and overnight melatonin production were significantly and independently associated with diabetes [33].

Light exposure at night can shift the circadian rhythm of melatonin release into the morning hours so that a breakfast glucose intake tolerance test occurs at a time of high circulating melatonin [24]. When food coincides with the timing of high melatonin levels this leads to impaired glucose metabolism. Several studies [34,35] have found raised glucose and insulin responses to meals when exogenous melatonin was taken. Another study [36] found that insulin sensitivity was impaired in oral glucose tolerance test administered in the morning after truncated sleep when melatonin levels were high, with longer duration of elevated morning melatonin resulting in worsened insulin sensitivity.

New CIRCADIAN® Zirc™ Lighting Solutions

To manage the risk of obesity and diabetes, light fixtures should provide blue-rich light during the day and blue-depleted light at night. The key is not just to lower blue content but to make sure the lights remove enough blue at night to reduce the risk (i.e., fall within the range of minimal circadian disruption in Figure 7).

For example, CCT color tuning products that transition from 6500K during the day to 2700 K at night do not remove enough blue out of the light spectrum at night to prevent circadian disruption, melatonin suppression, and the risk of obesity and diabetes (Figure 7). While these CCT color tuning products may be marketed as “circadian” they still often rely on a blue pump and cause circadian disruption.

To address the risk of blue light, CIRCADIAN® ZircLight™ has introduced fixtures that contain a light engine with both a blue-pump LEDs for daytime use as well as a patented violet-pump LED for evening and nighttime use. The “night” LED removes over 90% of the bioactive blue content to minimize circadian disruption, and provides white light with a CCT of 3200K, and CRI of 80+. To control blue light exposure 24/7, the CIRCADIAN® ZircLight™ fixtures automatically switch between day and night LEDs based on location, time and season.
REFERENCES

ABOUT THE AUTHOR

MARTIN MOORE-EDE, M.D., Ph.D.

For over 30 years, Dr. Moore-Ede has been a leading expert on circadian clocks, and the health and safety risks faced by businesses that operate 24/7. After experiencing the challenges of fatigue as a surgeon-in-training required to work 36-hour shifts, Dr. Moore-Ede was one of the first to define the challenges of living, working, and sleeping in a 24-hours-a-day, 7-days-a-week world. As a professor at Harvard Medical School (1975–1998), he led the team that located the suprachiasmatic nucleus, the circadian biological clock in the human brain that controls the timing of sleep and wake, and pioneered research on how the human body can safely adapt to working around the clock and sustain optimum physical and mental performance.

In 1983, to implement circadian science in the workplace, Dr. Moore-Ede founded CIRCADIAN® which now helps over half of the Fortune 500 companies optimize 24/7 workforce productivity, health, and safety. In 2012, in response to the emerging evidence of the harmful effects of blue-rich LED light at night, Dr. Moore-Ede led the team that developed the first blue-depleted white LED lights for safe use at night, and established CIRCADIAN® ZircLight™, to market LED lighting systems which provide the correct blue dosage for optimal human health and safety according to the time of day, based on a comprehensive proprietary IP portfolio.

Dr. Moore-Ede graduated with a First Class Honors degree in physiology from the University of London, received his medical degrees from Guy’s Hospital Medical School, and his Ph.D. in physiology from Harvard University. He has published 10 books and more than 150 scientific papers on the physiology of sleep deprivation and circadian rhythms. Dr. Moore-Ede holds multiple patents on the spectral composition of light sources, and tools for assessing and mitigating fatigue risk including the Circadian Alertness Simulator (CAS), a scientifically validated fatigue risk model. He has served on multiple national and international committees and has received numerous awards including the Bowditch Lectureship of the American Physiological Society. He is a frequent guest on television (CNN, Today Show, Good Morning America, 20:20, Dateline, Oprah Winfrey, Nova, BBC), radio (NPR Fresh Air, Connection), and print media (Wall Street Journal, New York Times, Washington Post, Time and Newsweek). He has testified before Congressional committees on multiple occasions and advised government agencies on the health and safety of the 24/7 workforce in the US, Canada, and Europe.