

Lighting for Schools



The circadian rhythms and sleep-wake cycles of pre-school and very early elementary school aged children are relatively stable, but gradually shift toward a preference for late-morning wake times and late-onset sleep times [126, 127], culminating in greater delays during puberty and adolescence beginning around the age of 12-14 years [128, 129]. Research suggests that these pre-pubertal changes to sleep-wake cycles and circadian phase appear to begin around 5-7 years of age [130, 131].

The typical adolescent schedule of “late to bed and late to rise,” combined with highly structured school schedules requiring early start times, often leads to reduced sleep duration among students. This lack of adequate sleep is

compounded by keeping children in classrooms all morning, where they receive inadequate exposure to morning daylight for stimulating the circadian system and entrainment to the 24-hour solar day, especially during the dark winter months [132]. In late spring, if adolescents spend more time outdoors after school, their circadian rhythms may be delayed by evening daylight exposure [133]. Adolescents’ sleep can be even further compromised by nighttime exposure to self-luminous electronic devices (e.g., cellphones, tablets, laptops, etc.), which provide an alerting stimulus and suppress melatonin secretion [134]. In addition to circadian delay, evidence has also emerged suggesting that the endogenous circadian period is longer, sleep pressure accumulates more slowly, and the sensitivity to light by the circadian system is greater in adolescents than in adults, especially among those with delayed sleep phase disorder (DSPD) [135, 136]. In fact, a recent LRC show study show that adolescents (ages 15-17 years) are more sensitive to evening light from self-luminous devices than those in their twenties [134]. Both of these factors functionally delay the timing of the adolescent circadian clock, thereby contributing to later bed and rise times.

Pre-teens and adolescents

Pre-teens (K-5th grade)	
Time	CS
Wake - 3:00 PM	0.3
3:00 PM - 4:00 PM	0.3 → 0.1
4:00 PM - Bed	0.1

Teens (6th-12th grade)	
Time	CS
Wake - 12:00 PM	0.4
12:00 PM - 1:00 PM	0.4 → 0.3
1:00 PM - 3:00 PM	0.3
3:00 PM - 4:00 PM	0.3 → 0.1
4:00 PM - Bed	0.1

Pubertal development is associated with accumulating delay in the preferred timing of sleep and waking that contributes to significant reductions in total sleep time during adolescence [131, 137-145]. A report by the National Sleep Foundation states that, even though adolescents require as much sleep as they did as pre-adolescents (about 8.5 to 9.25 hours per night), they tend to fall asleep later (about 11:00 PM), averaging only 7 hours, 42 minutes of sleep per night at age 13. Total sleep time decreases even further to around 7 hours per night by the time this population reaches the age of 19 [146].

Characterized by the American Academy of Sleep Medicine as a circadian sleep-wake disorder involving sleep onset that occurs significantly later than desired bedtimes and societal norms [151], DSPD is common among adolescents [152-154] and increases their susceptibility to chronic sleep restriction and associated detrimental outcomes [155]. Individuals with DSPD exhibit long sleep latencies when attempting to sleep at conventional bedtimes. Patients are diagnosed with DSPD if these symptoms cause distress and impairment and if they persist for at least 3 months. More than

8% of adolescents may have DSPD [155-157], which increases their risk for poor scholastic performance and behavioral problems.

A lighting intervention designed to deliver light beginning in the early to mid-morning (after 9:00 AM) and extending throughout the school day and reduce evening light exposures (e.g., wearing orange-tinted glasses, controlling use of self-luminous devices), may help shift the timing of sleep in adolescents. Successful light therapy in this population will likely involve both school administrators and family members.

Special needs students



Special education classrooms provide specialized learning environments for students with learning difficulties or physical disabilities. The most common diagnoses among students include specific learning disabilities, speech/language impairments, health impairments, autism, developmental delay, intellectual disability, emotional disturbance, multiple disabilities, hearing impairment, and orthopedic impairment [176]. Students diagnosed with these conditions tend to be more sensitive to stimulus in the lighted environment and are susceptible to overstimulation from bright and/or flickering light [177], which can lead to repetitive behavior and agitation, tics, and epileptic episodes [178]. Older classrooms commonly

Special needs (K-12th grade)	
Time	CS
Wake - 2:00 PM	0.3
2:00 PM - 3:00 PM	0.3 → 0.2
1:00 PM - 3:00 PM	0.2
3:00 PM - 4:00 PM	0.3 → 0.1
4:00 PM - Bed	0.1

have 2×4 fluorescent troffers that typically have a flicker frequency of 120 Hz that can create a stroboscopic effect, with flicker noticeability increasing with age of fixture [179]. A few options to mitigate the effects of flicker include integration of daylight with electric lighting, introduction of constant-current LEDs, and ensuring luminaires are compatible with their dimming system. The use of blue light is a viable solution for creating a classroom environment that reduces light stimulus while still ensuring that students' circadian needs are met. In addition to a programmed light schedule, manual override options should be available for teachers.

College students



The adolescent pattern of late sleep onset and late waking continues through students' college years [162-166]. One study indicated that 73% of college students reported at least occasional sleep problems [163], while another showed that more than 48% of students suffer from sleep debt. Student stress, social habits, and educational demands contribute to these problems. One large-scale study of college students found that about 60% report poor sleep quality [167], and another study reported college students' difficulty falling asleep (15%), frequent nighttime waking (26%), and fulfillment of the diagnostic criteria for insomnia (8%) [168].

College- Early riser	
Time	CS
Wake - 5:00 PM	0.3
5:00 PM - 6:00 PM	0.3 → 0.2
6:00 PM - 8:00 PM	0.2
8:00 PM - 9:00 PM	0.2 → 0.1
9:00 PM - Bed	0.1

The tendency to delay bedtimes and extend rise times increases the risk for serious consequences of sleep debt [149, 167, 174]. Sleep quality is closely linked with mental and physical health and well-being, thus intervention programs aimed to improve sleep in this population are recommended [162, 165-167, 175].

College- Night owl	
Time	CS
Wake - 5:00 PM	0.3
5:00 PM - 6:00 PM	0.3 → 0.2
6:00 PM - 10:00 PM	0.2
10:00 PM - 11:00 PM	0.2 → 0.1
11:00 PM - Bed	0.1

A lighting intervention designed to deliver light upon waking and extending throughout the day and reduce evening light exposures (e.g., wearing orange-tinted glasses during evening use of self-luminous devices), may help shift the timing of sleep in college students. Light therapy has also the potential to improve mood and depression in this population. Successful lighting intervention in this population would best involve educational facilities managers (e.g., lecture theater, classroom, and dormitory lighting) and the active participation of the students themselves.

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