Eneref Institute

PR FOR PLANET EARTH™

A REPORT ADVOCATING FOR SOCIALLY RESPONSIBLE SUSTAINABLE DEVELOPMENT

CLASSROOMS OPTIMIZED WITH NATURAL DAYLIGHT INCREASE **STUDENT PERFORMANCE**

ENEREF INSTITUTE EXAMINES THE IMPORTANCE OF THE NEW WELL BUILDING STANDARD FOR DAYLIGHT IN CLASSROOM DESIGN.

Today we know that optimizing daylight as a light source in school buildings improves students' academic performance. Daylight drives natural circadian rhythms of hormones, organs, tissues and the sleep-wake cycle. School planners have an opportunity to design lighting that supports alertness, mood and cognitive functions. The new WELL Building Standard for daylighting is designed to reinforce a normal circadian rhythm and improve visual acuity. To enhance student performance, architects should provide illuminance recommendations that maximize natural daylight.

SYNCHRONIZING OUR CIRCADIAN RHYTHM REQUIRES PERIODS OF BRIGHTNESS AND DARKNESS.

Our biological circadian rhythms operate on nearly a 24-hour clock, but they need to be synchronized to night and day. Many physical, mental and behavioral changes are regulated by our circadian rhythm.

Careful architectural planning and utilization of daylight to illuminate rooms, in conjunction with lighting controls to dim tunable-white LED electrical light sources, is not only efficient for buildings but also healthy for occupants, both students and faculty alike.

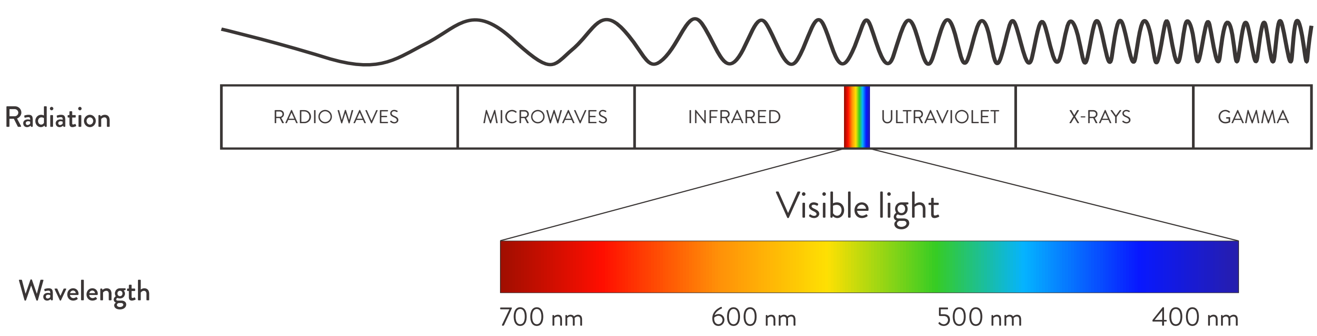
NEW KNOWLEDGE OF THE IMPORTANCE OF WELLNESS DEMANDS DAYLIGHT

Many recent research discoveries should compel schools to specify natural interior daylight as a primary light source in classrooms, as advised by the WELL Building Standard. In 2012, the American Medical Association adopted a policy statement citing evidence that links circadian rhythm disruption to impacts on human health. In fact, the 2017 Nobel Prize in Medicine was awarded to three scientists for their discoveries of the molecular mechanisms underlying circadian rhythm.

Our circadian rhythm operates on a 24-hour cycle that controls our physiology—not only sleep and wakefulness but many physical, mental and behavioral functions as well: blood pressure, heart rate, alertness, body temperature and reaction time. The circadian system ensures peak performance during physical activity and efficient energy harvesting during the active phase of our day. Perhaps more importantly, circadian rhythm regulates changes in our immune function, cell cycle, DNA damage response and tumor suppression.

To maintain properly synchronized circadian rhythms, the body requires periods of both brightness and darkness. Improper lighting design can lead to a drift of the circadian phase by altering the light-dark cycles to which our bodies are exposed. This change can

ELECTROMAGNETIC SPECTRUM



turn on, or turn off, genes that control the molecular structure of our biological clocks, in turn speeding up, slowing down or even resetting our endogenous circadian rhythmicity.

According to the paper "Circadian Rhythm and Sleep Disruption" by LIGHT Laboratories of the University of Leeds, poorly designed artificial electric lighting can disrupt the molecular clocks that regulate the temporal dynamics of cellular activities.

CIRCADIAN CLOCK GENES REGULATED BY SUNLIGHT

In 1984, researchers from the Department of Biology at Brandeis University (and later in 2007 by Lamont et al, and others) determined that certain molecules are expressed at different times throughout the day-night period. Some of these molecules are the product of the so-called "circadian clock genes"; in particular, a set of "period genes" are key circadian rhythm regulators. (Other circadian clock genes have also been found to regulate the rhythm: Clock, Bmal1, three Period genes and two cryptochrome genes.)

The biological rhythm of circadian clock genes is reset on a daily basis by the hormone melatonin, which is stimulated and regulated by the sunlight received by our eyes. Using natural daylight to illuminate schools would thus help students' bodies regulate melatonin, reinforcing circadian wellness and improving performance.

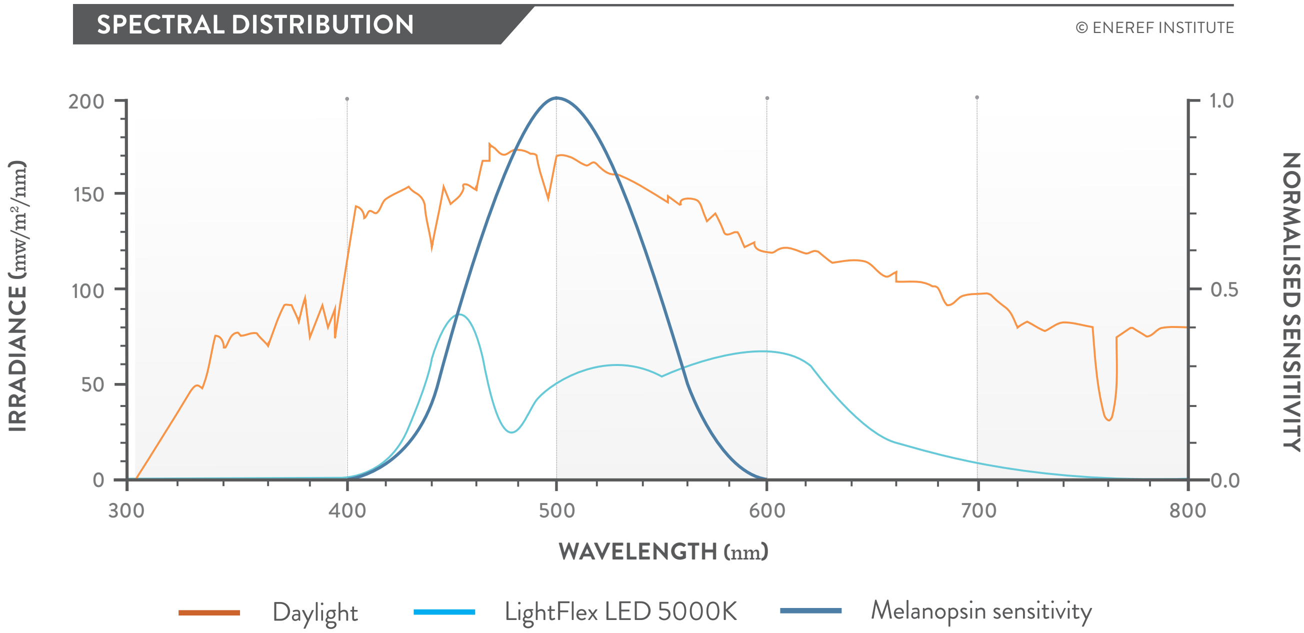
A paper by the Department of Molecular Biology at McGovern Medical School in Houston found that mice with the ablation, or removal, of genetic functions of the period gene lost circadian control. The Brandeis researchers found similar results.

NEWLY DISCOVERED PHOTOSENSITIVE RETINAL GANGLION CELLS NEED 480NM

The day-night cycle plays a key role in melatonin secretion, which dictates the 24-hour pattern of period gene expression in tissues. In 2002, Brown University scientist David Berson discovered an entirely new class of photosensitive light receptors, independent of rods and cones, in the retina. While rods and cones are responsible for the analysis of images, patterns, motion and color, these new receptors, he found, play a different role.

These photoreceptors, called

IPRGC SENSITIVITY PEAKS AT 480NM



RODS AND CONES

Electron microscope image of rod and cone photoreceptor proteins in the cells of the retina.

intrinsically photosensitive retinal ganglion cells (ipRGCs), are the primary photoreceptors involved with synchronizing our circadian system. Unlike rods and cones, ipRGCs are non-image forming; instead, they project signals to a number of areas in our brain to reset our clock and also drive other reflex responses to light. While ipRGCs comprise only a small fraction of the total ganglion cell population in our retina, they amplify light by several orders of magnitude and initiate a cascade of neural events. A single ganglion cell can "see" just a few photons of light.

The full visible wavelength light spectrum our eyes can see ranges from about 400nm to 700nm, which, unsurprisingly, is what we receive from sunlight. ipRGCs are most sensitive to light at short wavelengths between 446nm and 477nm (cyan). Short-wavelength light increases alertness by suppressing melatonin production. A lack of exposure to melatonin-suppressing light wavelengths can result in impaired alertness and diminished performance, according to a 2011 paper published by Philadelphia-based Thomas Jefferson University Department of Neurology.

Unfortunately, most electric lighting in the 3000-3500k range offers much less light at this wavelength than daylight, essentially blinding the primary photoreceptors that synchronize our circadian system. Without any cyan-color, short-wavelength light, our rods and cones still create an image for us to see, but our circadian photoreceptors are rendered ineffective. This is one reason why poorly designed artificial lighting in schools can have such a negative effect on student performance; without the proper wavelength of light, students' natural circadian rhythm is disrupted.

The primary role of ipRGCs, therefore, is to signal light for largely subconscious, non-image-forming visual reflexes, including synchronizing or shifting the phase of our circadian clock, maintaining alertness, detecting contrast and constricting our pupil reflex dilation. Much of this was examined by Kwoon Y. Wong of the Department of Ophthalmology & Visual Sciences at the University of Michigan.

SIGNIFICANCE OF IPRGCS IN REGULATING CIRCADIAN RHYTHM

Rods, cones and the newly discovered retinal ganglion cells (ipRGCs) are individual cells in our retina that contain light-absorbing photoreceptor proteins called opsins. The opsins within cones absorb different wavelengths of light to allow us to see three different colors: red, green and blue. The opsin in ipRGCs, however, is a completely different class of photoreceptor known as melanopsin. Unlike the opsins in rod and cone cells, melanopsin doesn't contribute to vision; instead, it serves the role of setting circadian rhythm and other functions.

Evidence of the significance of ipRGCs in regulating circadian rhythm was famously discovered by Robert Lucas, Professor of Neuroscience at the Imperial College School of Medicine in London. Lucas's research on the importance of melanopsin expression by ipRGCs is the basis for the WELL Building Standard. In the Lucas experiment, mice

FACT

OPTIMIZING DAYLIGHT IMPROVES ACADEMIC PERFORMANCE.

School planners have an opportunity to design lighting that supports alertness, mood and cognitive functions.

ON EXPOSURE TO DAYLIGHT, THE PRODUCTION OF MELATONIN IS REDUCED, IMPROVING COGNITION.

Careful architectural planning and utilization of daylight to illuminate rooms, in conjunction with lighting controls to dim tunable-white LED electrical light sources, is not only efficient for buildings but also healthy for occupants.

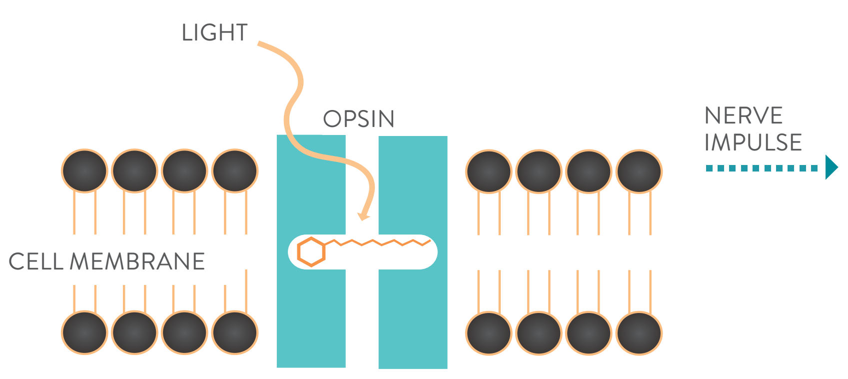
that had been engineered to lack rods and cones (think, three blind mice) but still had ipRGC photoreceptors were able to orient themselves to day-night cycles using a light source that mimicked natural day and night. In another experiment done by the Ophthalmology Department of the University of Michigan, mice with only ipRGCs were able to measure ambient light intensity, mediate pattern vision, discriminate brightness and detect contrast.

SCN OSCILLATOR SYNCHRONIZES OUR CIRCADIAN CLOCK

When light strikes the retina, melanopsin converts the photon into an electrical signal, sending the impulse on a labyrinth trajectory, first to the hypothalamus and then to the pineal gland. An area of the brain called the suprachiasmatic nucleus (SCN) in the anterior hypothalamus is a self-sustaining oscillator for regulating our circadian rhythm, but it is not tuned perfectly to a 24-hour day. It needs to be reset, or entrained, to the light/dark cycle of the solar day by melatonin, the neuro-hormone that makes us sleepy.

The melanopsin protein in the ganglion cell triggers the SCN, which in turn instructs the pineal gland to actually produce melatonin. When there is less light, like at night, the SCN tells the brain to make more melatonin to induce sleep. On exposure to daylight, the production of melatonin is reduced, thereby preventing drowsiness and improving attention and cognition.

Research by the University of Illinois's Department of Structural Biology as well as the University of Texas Southwestern Medical Center found that the SCN influences mood, and, most importantly for students, learning abilities. In fact, sufficient sleep, which is regulated by melatonin production, has its largest effects on attention, memory and cognitive throughput according to a 2013 paper entitled "Circadian Rhythms, Sleep Deprivation, and Human Performance" by researchers from the Perelman School of Medicine at the University of Pennsylvania. According to Johns Hopkins University's Tiffany M. Schmidt, light received by ipRGCs is by far the most potent circadian photoentrainment cue—or synchronization mechanism.



LIGHT STRIKES THE RETINAL MOLECULE

MELANOPSIN SERVES THE ROLE OF SETTING CIRCADIAN RHYTHM AND OTHER FUNCTIONS.

Improper lighting design can lead to a drift of the circadian phase by altering the light-dark cycles to which our bodies are exposed. A lack of exposure to melatonin-suppressing light wavelengths can result in impaired alertness and diminished performance.

STUDIES DEMONSTRATING VALUE OF DAYLIGHT ON STUDENT PERFORMANCE

Multiple studies have shown that students exposed to short-wavelength daylight in the morning had improved circadian rhythm. In a study called "Daylighting in Schools: An Investigation into the Relationship between Daylighting and Human Performance," commissioned by the Pacific Gas and Electric Company, the Heschong Mahone Group (HMG) found a high correlation between schools that reported improvements in student test scores and those that reported greater amounts of daylight in the classroom. (Heschong Mahone has since joined TRC Companies, Inc.)

The HMG study looked at the effect of daylight on student performance and established a statistically compelling connection. HMG obtained student performance data from 21,000 students in three elementary school districts, each of which had different curricula and teaching styles, different school building designs and very different climates. Yet the results of the study showed a consistently positive and highly significant correlation, supporting the proposition that there is a valid and predictable effect of daylight on student performance.

In the district with the most detailed data, it was found that the students with the most daylight in their classrooms progressed 20% faster on math tests and 26% faster on reading tests in one year than those with the least. Students in classrooms with the largest window areas were found to progress faster than those with the least. Additionally, students who had a well-designed skylight in their classroom, one that diffused daylight evenly and allowed teachers to control the amount of daylight entering the room, also improved 19% faster than those without a skylight.

VISUAL ACUITY ENHANCED UNDER DAYLIGHT

Visual acuity (the clarity and sharpness to discern letters) is greatly enhanced under daylight because the sun renders all wavelengths of light within the visible color spectrum. When we perceive the color of an object, what we're really seeing is the reflection of light. Electric lights only emit light radiation in bits and pieces of the visible spectrum, so if a portion of the wavelength isn't in the electric light source to begin with, that color can't be reflected. Color, therefore, is not an intrinsic property of an object; rather, the appearance of an object's color depends on the light illuminating its surface.

Architects measure colors in degrees Kelvin. The higher the color temperature, the bluer the light. Lower color temperatures are more reddish. The color of bright daylight without clouds is a blueish 6000K, while a reddish sunset is about 3000K. (In quantum physics, Kelvin color temperature is derived from a theoretical object, called a blackbody radiator, heated high enough to give off light.)

Although we receive all visible wavelengths from the sun during

TUBULAR DAYLIGHTING SYSTEM

Eneref found only LightFlex LED integrates tunable LEDs into a tubular skylight.

all times of the day, we receive more of the 480nm cyan wavelength at midday, which inhibits melatonin production. As the sun goes down, we receive fewer blue wavelengths and more red, prompting our bodies to make melatonin. Night-time levels of melatonin are at least 10-fold higher than those in daytime.

TECHNOLOGICAL SOLUTIONS TO LIGHTING IN CLASSROOMS

Visual daylight design is essentially circadian lighting design, which controls for glare (Annual Sunlight Exposure) and the amount of daylight that reaches a given space (Spatial Daylight Autonomy).

"Lighting designers should aim to achieve Spatial Daylight Autonomy values of 75 percent or higher in classrooms," says Kevin Van Den Wymelenberg, an associate professor at the University of Oregon, where he directs the Energy Studies in Buildings Laboratory.

Fortunately, many lighting manufacturers sell luminaires—electric lighting—that can help synchronize circadian rhythm. Using "tunable-white" LEDs, the luminaires modify their color temperature between warm and cool white light by mixing specific wavelengths of LEDs. Still, only sunlight offers the full, dynamic spectrum of light waves ideally suited for our 24-hour biological circadian rhythm.

Therefore, given what is readily available in the market, Eneref Institute recommends a lighting combination of natural interior daylight via windows and skylights with tunable-white LEDs. When access to the roof is available, skylights should be the primary light source. Skylights are the best means of providing general ambient lighting to the interior of a space, but standard skylight units are often not feasible in drop or suspended ceilings, common in US school buildings. For drop ceilings, a tubular daylighting system is the only option to bring in natural daylight from the roof.

There are a number of skylights on the market today that can accommodate a drop ceiling. However, Eneref found only one daylighting system that delivers daylight in a tubular configuration and also incorporates inset tunable-white LEDs. The system, named LightFlex LED, is manufactured by Sunoptics, an Acuity Brands company, which is a North American market leader in lighting and building management solutions.

An integrated photocell sensor and control adjusts the tunable-white LEDs to optimize the available natural daylight in the space while minimizing energy load of the LEDs. The sensor detects the amount of outside natural daylight and triggers the lighting controls to supplement the daylight with the LEDs only when electric light is needed to meet the desired light levels. An integrated louver can limit the amount of daylight when less light is needed, such as during AV presentations.

The tunable-white LEDs in LightFlex LED enable color temperature controls from 2700K to 6500K to provide color uniformity between the electric and natural light sources. To promote ipRGC photoreception, LED light sources should be biased towards the blue regions of the visible spectrum during the day. In the evening, to mimic dusk, LEDs should be set to a

EQUIVALENT MELANOPIC LUX MEASURES LIGHTING'S EFFECTS ON THE CIRCADIAN CYCLE.

Primary and secondary schools should have at least 125 EML for 75 percent, or more, of the classroom desks for at least 4 hours per day.

warmer color temperature, which increases melatonin production.

NET-ZERO ENERGY OPPORTUNITY

Designing a classroom with natural interior daylight is more complicated than designing with electric lighting because daylight presents a wide range of solar altitudes, angles and light transmittances. However, outfitting a building with daylight and sensing controls can reduce the energy used for electric lighting by 20 to 60 percent. Electric lighting in buildings consumes more than 15 percent of all electricity generated in the United States, according to the U.S. Department of Energy and the U.S. Energy Information Administration. Still, daylight projects should not be driven by energy-payback calculations alone but should also integrate improved student performance metrics.

The national ASHRAE Standard for building codes mandates daylighting in certain building types with lighting controls for top-lighting skylights and side-lighting windows. In fact, nearly all building codes and standards recommend or specify natural interior daylight, including California Title 24, New York's NYSERDA, IECC, IGCC, LEED and the recently developed WELL Building Standard. To help cover the costs of daylight projects, Eneref Institute advocates for redefining daylight as "solar" or "renewable" to provide daylight design the sophisticated financing opportunities available for photovoltaic solar panels.

The WELL Building Standard has put forward a new metric for measuring lighting in schools and other buildings—one that's weighted to include ipRGC photoreception. Called the Equivalent Melanopic Lux (EML), it measures lighting's effects on the circadian cycle and includes a ratio of the total spectral power distributions (all the visual color temperatures) to the melanopsin-sensitive light distributions. The WELL Standard compels early, primary and secondary schools to have at least 125 EML for 75 percent, or more, of the classroom desks for at least 4 hours per day.

Every photon of light triggers a complex network of neural and endocrine system responses that send hormones coursing through our bloodstream to influence the brain, body and behavior. It is for this reason that daylight should be used in conjunction with tunable-white LEDs wherever practicable. However, tunable-white LEDs alone can't perfectly mimic daylight. Contributions to our metabolism come from all our opsins (rods, cones and ipRGCs) and depend on the intensity of the light stimulus and the variety of spectral light colors. Photoreceptors are not equally sensitive to all light at all wavelengths. Our biology expects to receive light "weighted" in favor of what sunlight delivers throughout the day.

The challenge for LED lighting system manufacturers is complex—to create LEDs with spectral wavelengths equivalently weighted to the spectrum of daylight throughout the day, and perhaps throughout the annual seasons. The simplest solution for school sustainability officers and architects is to specify natural interior daylight as their primary light source.

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LEAD BY EXAMPLE.

THE RIGHT TO DAYLIGHT INITIATIVE
IS A CAMPAIGN TO PRESERVE OUR NATURAL RESOURCES AND ENJOY THERMAL COMFORT IN OUR HOMES AND BUILDINGS.

TO ACCOMPLISH OUR MISSION, Eneref Institute launched the Right To Daylight campaign to champion solutions in line with our mission and deliver sound ideas to significant market influencers. The initiative is designed to encourage responsible behavior of public and private organizations, municipalities and corporations with common sense solutions that can achieve effective results.

Our Virtual Campus is the repository for our Advocacy Reports and Web Forums. **Visit eneref.org.**

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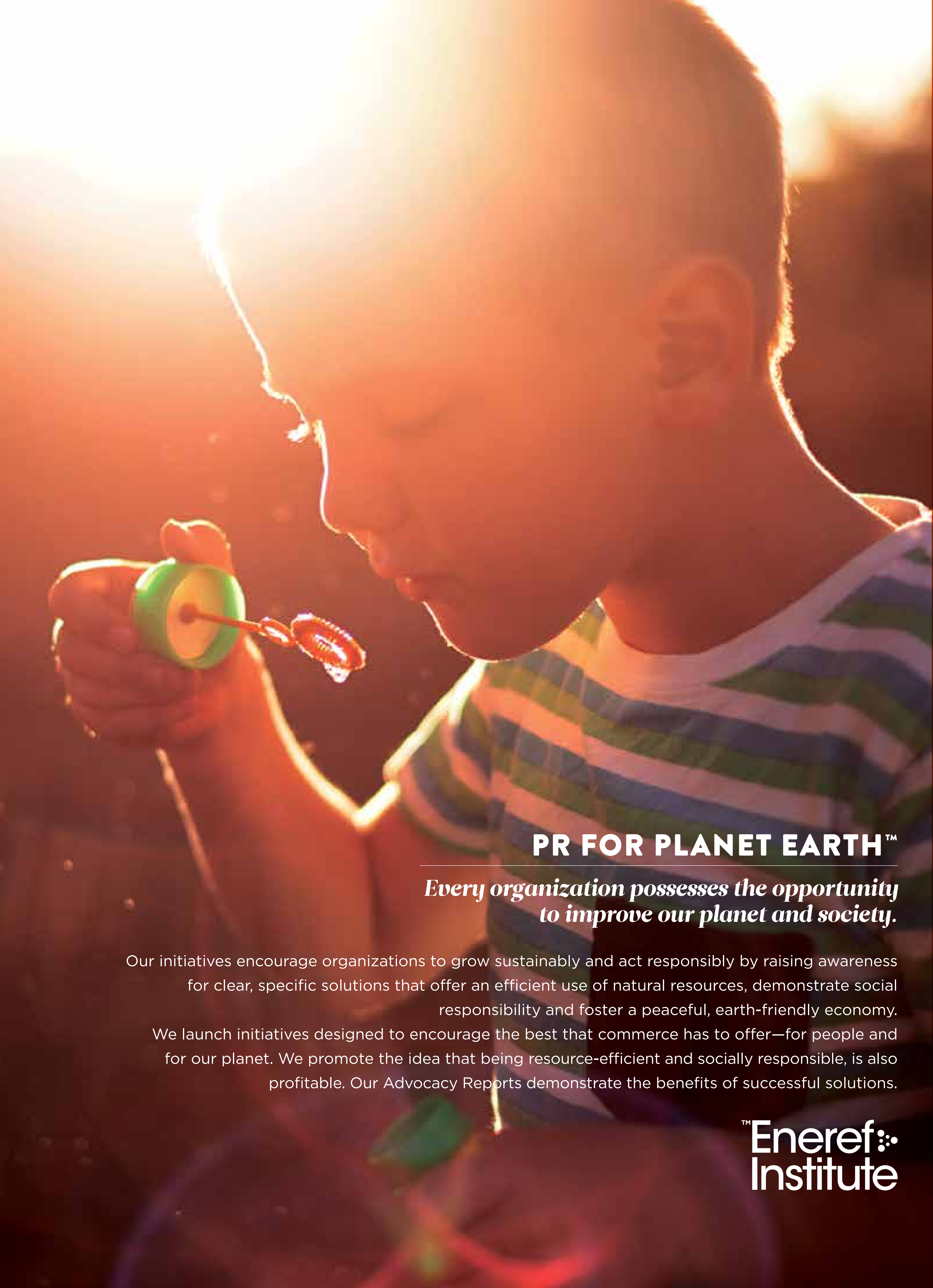
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