



Science and Technology Committee

Corrected oral evidence: The effects of artificial light and noise on human health

Tuesday 7 March 2023

10.10 am

[Watch the meeting](#)

Members present: Baroness Brown of Cambridge (The Chair); Lord Borwick; Viscount Hanworth; Lord Holmes of Richmond; Lord Krebs; Lord Mitchell; Baroness Neuberger; Baroness Neville-Jones; Baroness Northover; Lord Rees of Ludlow; Lord Sharkey; Lord Wei; Lord Winston.

Evidence Session No. 2

Heard in Public

Questions 16 - 26

Witnesses

Dr Christopher Kyba, Researcher, German Research Center for Geoscience, Helmholtz Centre Potsdam; Professor Dr Manuel Spitschan, Professor of Chronobiology and Health, Technical University of Munich; Professor Shantha Rajaratnam, Professor of Sleep and Circadian Medicine, Monash University.

USE OF THE TRANSCRIPT

This is a corrected transcript of evidence taken in public and webcast on www.parliamentlive.tv.

Examination of witnesses

Dr Christopher Kyba, Professor Dr Manuel Spitschan and Professor Shantha Rajaratnam.

Q16 The Chair: I welcome our witnesses to the committee's second evidence session of its inquiry into the effects of artificial light and noise on human health. Today we focus on light, and we have three witnesses joining us, from Germany and Australia: Dr Christopher Kyba, a researcher at the GFZ German Research Centre for Geosciences at the Helmholtz Centre in Potsdam; Professor Shantha Rajaratnam, Professor of Sleep and Circadian Medicine at Monash University and chair of the Sleep Health Foundation; and Professor Manuel Spitschan, Professor of Chronobiology and Health at the Technical University of Munich. The session is being broadcast on parliamentlive.tv, and a transcript will be made available to our witnesses shortly after the meeting to make any minor corrections.

If you think of anything that you wish you had told us while the session is going on or shortly after, or if there is any data that you can provide us with that would perhaps help us in our inquiry, we would be delighted to receive that from our witnesses after the session.

I will launch the session with the first question. Could you, by way of introduction, give us a quick overview of some very basic questions? What are the main sources of artificial light that humans are exposed to, and do you have a formal definition of what constitutes light pollution?

Dr Christopher Kyba: Thank you very much for inviting me to be here today. It is a pleasure to be invited. I work with various different methods, ranging from satellites to people on the ground counting up light sources to look at what types of lights there are. We can say that the answer to this question depends very much on your context. If you are in a rural area, you are much more likely to have a large fraction of light due to streetlights rather than, for example, due to signs and advertising. Two other areas that often cause problems for outdoor light in rural areas are sports lighting and greenhouses.

In the urban environment, you start to have much larger exposure from things like signs, advertisements and architectural lighting, which in downtown environments can become quite bright on people's bedroom windows. I specialise in outdoor light at night, so I am talking here about the exposure to outdoor light rather than indoor light, which of course is very important.

Finally, I would like to address the question about light pollution with the answer that in my opinion it is a useful term for gathering a lot of different aspects of light. However, it is generally better to talk about specific things such as glare or melatonin suppression, or light trespass rather than using the term "light pollution", because that term incorporates many different aspects.

Professor Shantha Rajaratnam: I would just add to Dr Kyba's description that we also differentiate indoor and outdoor sources of

lighting, and of course, when we think of indoor lighting, we also acknowledge the light sources, which are particularly relevant when we start to consider the impacts on human health.

Professor Dr Manuel Spitschan: There is another type of light source that we need to consider that is emitting, which is self-luminous displays that we might use, in particular in the evening—tablets, laptops and smart phones—all of which forms part of this construct of light pollution or artificial light at night.

Q17 **The Chair:** Thank you. We will be particularly interested in the impact of displays on children in their bedrooms and at night, and so on, so thank you for raising that.

Is there any mapping in any countries around the world of light exposure patterns? Are there any light-mapping databases or requirements to map light pollution in any countries that you know of, perhaps in an equivalent way to the way we might map noise pollution?

Dr Christopher Kyba: We have satellite data that comes primarily from a weather satellite operated by the United States. However, that is at relatively low resolution, so you do not distinguish individual houses. It is important to note that it has not yet been established that there is a correlation between what satellites observe from space and how much light arrives through people's windows. For physical reasons, that correlation must exist, but, as far as I know, only two studies have looked into this. One used a device that was too insensitive to measure the indoor light exposure.

If you want to understand these effects, you need to get right into bedrooms, because you can imagine that there is a very large difference, depending on whether your room faces the street or the backyard, and on whether you are using blinds or leave a TV on inside the room. If you want to look at exposure mapping, you need to go to the individual level—the bedroom, if that is what you are interested in—or to devices that are with or physically on the person to monitor them over the course of their daily exposure.

The Chair: Thank you. That is very interesting.

Q18 **Lord Borwick:** What are the major impacts of artificial light on human health that we know about and are most confident about, and how do we know that they are bad for human health? Dr Kyba?

Dr Christopher Kyba: I thought I would leave this question to someone else, because I am a physicist, not a health expert. I will say very briefly that we know very well that the pattern of exposure to daylight during the day and exposure to light in the evening all works together to produce this impact, so it is very clear that changes in exposure to light compared to the historical patterns that people were exposed to changes the pattern of sleep.

However, when we talk about sleep, it should be remembered that another big problem that society faces is early wake-up times and many

people waking up with alarm clocks. Those two things work together, and when you talk about the impact of artificial light you cannot disconnect it from the fact that we are all artificially shortening our sleep with alarm clocks.

Lord Borwick: Professor Rajaratnam, do you have any comments from Australia for us? We seem to have lost communication.

The Chair: Shall we go to Professor Spitschan first?

Professor Dr Manuel Spitschan: I would like to expand on Dr Kyba's description and unpack a bit of what we typically call the non-visual effects of light. We have sleep-wake cycles. In general, we consider the synchronisation of our biological clocks and our sleep-wake behaviour with the external light-dark cycle to be one major impact. There is also the suppression of certain hormones, such as melatonin, and the modulation of alertness. More recently, there have been studies establishing a link between light exposure at night and the impairment of cardiovascular and metabolic function. In neuroscience or chronobiology, we would summarise all these things as coming under the non-visual effects of light, which are separate from the mechanisms that serve vision and visual function.

There are other effects that are important to keep separate. These include the photochemical effects of light, which cause damage in retinal tissues. This is usually associated with very bright light sources such as the sun or welding arcs. These are summarised under the heading of blue light hazards; I suspect there will be questions on this later. It is important to keep blue light hazards as a phototoxic phenomenon separate from the circadian, neuroendocrine or non-visual aspects of light exposure.

Lord Borwick: You are saying that we know that there are effects on human beings. Do we know that they are harmful?

Professor Dr Manuel Spitschan: When it comes to the non-visual effects of light, we see converging evidence that bright light exposure at night or in the evening disrupts our circadian system. We can shift our circadian system, and we can suppress the production of hormones that are usually produced by the body. In particular—these are the acute effects that we typically measure—we also have evidence that long-term exposure and disruption of the circadian clock will have harmful consequences for mental and physical health.

As for the photochemical effects, there is clear evidence that very bright light exposure is damaging. It is very unlikely that we would typically be exposed to these light levels, but these effects exist, and they could cause damage to tissues.

Lord Borwick: What is the nature of the evidence that disruption of the circadian system is harmful to humans? Does it reduce life expectancy or have other effects?

Professor Dr Manuel Spitschan: Basically, there is a converging set of evidence. First, there are laboratory studies in which very controlled light

exposures lead to short-term consequences. There are also large-scale studies that have associated, for example, time spent outdoors with impacts on sleep quality and mood.

Lord Borwick: But it is very hard to identify whether the positive effects of time spent outdoors are more important than the negative effects of light.

Professor Dr Manuel Spitschan: Yes. Altogether, I consider there to be converging pieces of evidence that speak to the role of good light exposure in supporting the circadian system. From there, we can see a link between the negative effects and impaired cardiovascular or metabolic function, an increased risk of developing mental health issues, and so on.

Professor Shantha Rajaratnam: To add to what my colleagues have said, I agree with Professor Spitschan that there is converging evidence from very well-controlled laboratory studies and epidemiological evidence. If we bring these together, there is a sufficient basis at this point at least to postulate that there is a harmful effect on human health of light exposure at night.

A recent review by a group in China, published just this year in the *Journal of Environmental Sciences*, reviewed the evidence over the past five years and looked at the impact of light at night on health outcomes such as obesity, mental health disorders, cancer, sleep disorders, cardiovascular disease and diabetes. This was based largely on epidemiological evidence. I am happy to supply the committee with that paper afterwards.

As for the line of evidence on the circadian system being acutely sensitive to the effects of light, we now understand the physiology of that pathway well. We also understand that the disruption of circadian rhythms is associated with a number of adverse health outcomes. These can occur very rapidly, and we have been able to demonstrate that in tightly controlled laboratory studies. For example, if we systematically disrupt the circadian system in humans, within days we alter glucose regulation, appetite regulation, and a number of other variables that would strongly predict and lead to adverse health outcomes. That is why, as Professor Spitschan said, there is converging evidence that brings the physiology together with what we are observing in epidemiological studies.

Dr Christopher Kyba: It is also worth thinking about the acute effects for people living in intensive care wards. The impact of both noise and light in that environment is very disruptive to sleep. As far as I know, it has been demonstrated that interventions to reduce the amount of light and noise in those healthcare settings can really help patients. As the committee is looking at this issue from a broad perspective, I hope you will also consider that very particular and important aspect of exposure to light and noise.

The Chair: Thank you. There were a lot of nodding heads around the table on that point, including Baroness Neuberger's.

Baroness Neuberger: I chair two hospitals with intensive care units, so

we are very aware of this. How much hard evidence is there of that disruption and the quantitative effects of reducing the amount of light or noise?

Dr Christopher Kyba: I am not the right person to answer that question. I maintain a large database of such studies, so I can try to look for one after this meeting is over. Typically, I have seen this is intervention studies; there was an intervention in a hospital to lower the amount of light or noise or have patients sleep with eye masks. Those sorts of things have generally had very positive outcomes for patients.

Q19 **Baroness Neuberger:** I have seen some of those effects in qualitative terms, but not in quantitative terms, so anything that you can give us would be really useful.

Much of what I was going to ask has already been asked by Lord Borwick, but do any of you think that we can make any kind of economic assessment of the health impacts from artificial light? That is quite a broad question.

Professor Shantha Rajaratnam: That is a broad question. The Sleep Health Foundation in Australia, for example, has been working with health economists to quantify different aspects of sleep health, as have a number of the other sleep health bodies. I do not believe that a focused study has been undertaken on this, but it is entirely possible. As we have looked at other areas such as shift work and the contribution of sleep disorders to the health burden, et cetera, we should, on the basis of the evidence that is available, be able to attribute health risks associated with light exposure. However, I am not aware that that health economic study has been done.

Professor Dr Manuel Spitschan: I am aware of a study from the RAND Corporation from about five years ago that estimated more generally the effects of insufficient sleep on the economy; I think it estimated that about £45 billion is lost due to insufficient sleep¹. However, as Professor Rajaratnam described, that cannot be attributed only to artificial light exposure, although we are certain that a fraction of it could be attributed to it. It is just a question of whether it is 1%, 10% or 50%.

Q20 **Baroness Neuberger:** Lastly, I have a question about the mechanisms by which artificial lighting can affect human health and the impact of screens on eyesight. You have talked about welding and blue light. What about the effects of screens on children at night in their bedrooms, which we have talked a lot about among ourselves? Can you say anything about the mechanisms and whether that causes damage?

Professor Dr Manuel Spitschan: We can certainly talk again about the circadian disruption that might be caused by artificial light exposure. Displays, as they emit lights by whatever technological means, will be no different from any other light source. They will impact the same

¹ Hafner, M., Stepanek, M., Taylor, J., Troxel, W. M., Van Stolk, C. "Why sleep matters—the economic costs of insufficient sleep: A cross-country comparative analysis" *Rand Health Quarterly* 6:4 (2017).

physiological pathway that might cause, for example, the suppression of melatonin or a delaying of the circadian clock, as would your indoor lighting or TVs.

Specifically in children, there is another question that is not really related to the circadian or neuroendocrine effects of light, or to the photochemical damage that you might get from very bright light exposure—for example, from sun exposure—which is the development of myopia. That is a very different field from circadian physiology and circadian function. We have some evidence that light is really important in the prevention and delaying of myopia, but I would be hesitant to say that screens used at night play any role in non-ocular development.

When you look at light exposure from displays such as smartphones, there is another aspect that we should not ignore. There is a reason why these devices are used, which is that they are to some degree psychologically attractive to teenagers. There is a reason for checking Facebook modifications and WhatsApp messages, and so on, which in itself might cause some sleep disruption, but we already know that there is a pathway that would make blue light exposure or short-wavelength light exposure impact the circadian system.

Baroness Neuberger: Would either of the other two witnesses like to add anything? You are nodding.

Professor Shantha Rajaratnam: I would just add to Professor Spitschan's answer that we are very interested in this question, which is hotly debated: the extent to which these light emitting devices are contributing not to only what is perceived as an increased rate of sleep disturbances among children and adolescents but to mood and behavioural disturbances and learning impairments, and so on.

It is complex, because, as Professor Spitschan said, you have multiple contributing mechanisms that include the light emitted from the device that can shift the circadian clock; you have the attractiveness and the engagement of the device, and the arousal that can be caused depending on what the device is being used for; and the displacement of sleep that results from engagement with the device. These are complex factors that are driven partly by behaviour, the behaviour itself impacts sleep systems and the circadian system, and we know that both of these can contribute to the increased risk of the development of depression, anxiety, and cognitive and attention impairments.

We are being funded by the Australian Government, through the National Health and Medical Research Council and the Australian Research Council to do a longitudinal study to track adolescents from the ages of 12 to 18 and every year to follow them up to look at the state of their circadian system, the extent to which they are engaging in device use, and their sleep, cognitive function, mood assessments, et cetera. It is quite hard to disentangle all those factors, and, to my knowledge, no study has systematically pulled apart the contributing factors in order to design effective interventions. We also know that adolescence is a time when the circadian clock is naturally delaying, which also carries with it an increased risk of developing certain mood disorders, for example.

So it is complex, and the evidence is being gathered from studies such as the one we are doing.

Baroness Neuberger: Thank you very much. We look forward to hearing more about your study.

Q21 **Lord Mitchell:** Good morning and thank you for coming. To continue the conversation, do we understand how the intensity of light, the duration of exposure, and wavelengths of light factor into the impacts of artificial light on human health? Are these types of light exposure currently measured?

We have talked already about blue light, but we want to know what “blue light” actually means. Is there any evidence that different wavelengths of light have different health impacts or impacts on circadian rhythms? We know that there are different settings on our computers and iPhones, such as night light settings. Mine certainly does; when the sun sets, it flicks into a different mode and becomes orange. Is that just a marketing whizz, or does it have some real effect?

Dr Christopher Kyba: Again, Manuel and Shantha will be better able to answer this. Before I answer, I will say that there is an extremely large variability between different human beings and how they respond to light. One study that had 55 participants found that the difference in the amount of light required to suppress melatonin by 50% differed by a factor of 50 between the most sensitive person and the least sensitive person, and that is only with 55 study participants. In a country like the United Kingdom, you have a huge number of people. That is my pass-off to my colleagues, who are more expert in this area.

Professor Dr Manuel Spitschan: Over the past few decades, there have been systematic investigations into how intensity, the duration and the timing of exposure, and wavelength affect things like melatonin suppression and circadian phase shifting. We have a very solid evidence base for these studies; typically these are laboratory studies in which healthy volunteers spend one or two evenings in the laboratory while their physiological response is measured to specific lights that differ in intensity, duration, wavelength, and so on. Ultimately, we have gathered so much evidence that we can relate the wavelength-specific effects to the physiological mechanisms at the level of the eye that are relevant here.

About 25 years ago, a set of photoreceptors was discovered in the human eye that are sensitive to short-wavelength light and which are independent of the cones and rods that allow us to see. These cells, which are called the melanopsin-containing retinal ganglion cells, have a specific wavelength preference. They have a maximum sensitivity to wavelengths around 480 to 490 nanometres and then drop off for longer and shorter wavelengths.

That is really important, because when we are assessing or trying to measure the impact of light exposure on human health or the human circadian system, we need to take this wavelength preference—this

spectral sensitivity—into account. Typically, when we go out to measure aspects of light, we are not measuring the melanopic quantity, as it is called; we measure for photopic illuminance and lux. We might measure correlated colour temperature, but we are not at present routinely measuring the melanopic effects of light. We have a lot of laboratory evidence that these are the effects that we should focus on, but we are still lacking the routine deployment of measurement instruments and of metrics to make sense of the light data.

You also mentioned blue light. This is a very broad term that, depending on which literature you look at in biomedical sciences or neurosciences, has different meanings. That is a bit unfortunate because, as I mentioned earlier, in many case the circadian effects—the melanopic effects—of light are conflated with the blue light hazard effects of light.

We really need to come back to what function we are talking about. Is it photochemical damage, circadian disruption, or colour appearance? Only then can we determine the impact of a specific light source on whatever function we are interested in.

Professor Shantha Rajaratnam: I do not have much to add, but I will address Dr Kyba's earlier comment about the status of the epidemiological evidence and the limitations in what the satellite data have provided. I concur with Professor Spitschan's comment that we understand that if the circadian clock is the primary mechanism that we think is driving the elevated adverse health risks, we already know a lot about the properties of light that are relevant to the effect on the circadian clock.

These should be the properties that are measured in large-scale studies, because we will have a much clearer signal of whether the circadian system is implicated in the elevated health risks. If we measure the duration in intensity and the wavelength composition, especially taking into account the melanopic system, as well as the timing of the light exposure and the history of the light exposure, there are now good instruments that we can utilise to measure and quantify all those things at scale.

Dr Christopher Kyba: I would like to come back full circle to what I said at the very start of this round. Although it is true that we know a lot about the properties of light that are relevant to the effects on the circadian clock for the general population, it is well worth investigating the people who claim to have particular sensitivity to light. Over a third of the people living in a nursing home context in Japan, for example, claimed to have disrupted sleep due to light. Given the huge variability between human beings, there could be a significant impact on a subset of the population that is not reflected in studies which report the average effect on a large group of people. That area is currently understudied, and many people's impacts are potentially not being reflected in the literature, which is generally based on averages of relatively small groups.

Lord Krebs: Is there any evidence that light outside the visible range might affect these melanopic receptors—that is, ultraviolet—given that

they are short-wavelength sensitive?

Professor Dr Manuel Spitschan: In front of the virtual receptors in our eye we have a lens that does not transmit UV light, so in the outdoor environment, for example, it would be filtered out anyway. So we do not believe there is any evidence of UV light affecting these melanopsin cells, but, of course, UV more generally has phototoxic effects.

The Chair: Is there much work on the impact of the duration of the exposure to light on the circadian rhythm disruption?

Professor Shantha Rajaratnam: That is a very important question. Considerable work has been done, particularly in laboratory-controlled studies, to look at the duration of light exposure on melatonin suppression as one marker of circadian response, and on shifting the timing of the circadian clock, which is another marker of the circadian response. In general, we see a clear duration response function, so the longer the duration, the larger the responses that are observed. We also know from some elegant work that has been done in the United States that even very short durations of light exposure in humans can result in phase shifting of the circadian clock.

As to the complexity of this area, we also know that as the duration of the light exposure progresses in long-duration light exposures, which is what we are typically exposed to over the course of the day, the photoreceptor response changes. It is a dynamic system. We know, for example from some of the work done in collaboration with the Brigham and Women's Hospital, that the classic photoreceptor mechanisms may be involved earlier in the response and then, later, the melanopsin system may become more involved. We know that this is a dynamic system, the duration of light exposure matters, and the particular photoreceptor systems involved can also change over time.

Q22 **Baroness Northover:** We have already had a series of answers that have addressed this question. Do we currently have the scientific evidence base to make guidelines for recommended levels of artificial light exposure to avoid human health impacts, as the WHO has done for noise?

Professor Shantha Rajaratnam: When we think about guidelines for artificial light, there are a number of areas in which we could intervene, as we have discussed. If we think about the evidence that is emerging—for example, on indoor lighting and potentially evening light exposure—we have sufficient evidence now to make recommendations. I certainly take Dr Kyba's point about the large individual differences in sensitivity to light that have been observed, but at a population level we can make recommendations about appropriate evening light levels, for example, which would be a good start, and we could certainly also make some good recommendations about sleeping environments.

I also take Dr Kyba's point that in particularly vulnerable populations, such as in hospitals, age care settings, and so on, we should make recommendations early, because we know that circadian disruption will

have a significant impact not only on recovery but on the progression of disease in neurodegenerative conditions, and so on.

So there are particular areas where we have sufficient evidence to be able to make strong evidence-based guidelines. In other areas, we need to gather more evidence.

Professor Dr Manuel Spitschan: I would bring to the committee's attention an expert consensus recommendations paper² that was published last year based on a workshop that was held in Manchester, the Second International Workshop on Circadian and Neurophysiological Photometry, chaired by Professor Tim Brown from Manchester University and Ken Wright, who I believe is one of the expert witnesses who will speak in the next session.

In these expert consensus recommendations, we—I was part of that group—developed a set of criterion light levels that were recommended for the sleep environment, the pre-sleep environment and daytime light exposure. To get a sense of this, the recommendations included less than 1 lux melanopic EDI in the sleep environment, less than 10 lux melanopic EDI in the pre-sleep environment, and more than 250 lux melanopic EDI during daytime hours. EDI is just one way of characterising the melanopic effects of light—a specific metric. These recommendations are based on a thorough review of the existing laboratory evidence, supported by field studies that have provided convergent evidence. They are in a way limited to intensities of corneal light exposure, and not timing, but that is of course bounded by saying that in the sleep environment this should be less than 1 lux; there are specific time periods during which these light levels should be reached, and they are not specific to duration of exposure.

Baroness Northover: We may already have that material, but in case we do not it would be great to have a copy of the paper.

Dr Christopher Kyba: It is worth mentioning, however, that 1 lux is already very large in terms of the naturalistic environment. It is about a thousand times larger than starlight and many times larger than moonlight.

To return to the outdoor aspect, in many cases the light that is shining into people's bedroom windows and potentially—it is unclear—causing them issues with sleep is not doing any useful job. It may be lighting from advertising at a time when there are no pedestrians, or a streetlight that is poorly directed and does not need to shine on a window. So there is very little downside to addressing the kinds of things that can darken the sleeping environment without harming anyone, even the advertisers. In most situations, it is not really necessary to advertise late at night. There is room to act, even without everything necessarily being clear, in a way that harms very few people.

² Brown TM, Brainard GC, Cajochen C, Czeisler CA, Hanifin JP, Lockley SW, et al. (2022) Recommendations for daytime, evening, and nighttime indoor light exposure to best support physiology, sleep, and wakefulness in healthy adults. PLoS Biol 20(3): e3001571. <https://doi.org/10.1371/journal.pbio.3001571>.

Q23 Baroness Neville-Jones: I want to take the issue of intervention a tiny bit further and ask you about regulation. In the UK, there is very little evidence of regulation. There is a certain amount of guidance from the Government on how to use light when it concerns the planning system, but I do not think it goes beyond that.

Are there specific interventions amounting to regulation which you think it would be either valuable or urgent to put in place? Are you aware of anywhere where this sort of thing is being done? Do you see any countries or regions where light is being regulated intelligently?

It is question of whether the world of regulation is appropriate and whether we have reached the point where we know enough to put regulation in place. If you think that is the case, where do you think it would be most valuable or most urgent?

Professor Dr Manuel Spitschan: There is an opportunity here to bring to the attention of regulators and lighting manufacturers the novel metrics and the evidence base that underlie what we have talked about so far. As I mentioned earlier, when we are evaluating light sources, typically we look at photopic illuminance and correlated colour temperature. What we should look at in terms of human health impacts is the melanopic weighted light effects. This can be done with instruments that people already have.

Dr Kyba introduced the idea that there is a fundamental disconnect between what you can regulate and what arrives at people's eyes. You can imagine putting regulations in place for street lighting to be at a specific level. However, ultimately, depending on the geometry of the room, the type of window, how the walls are painted, what the colour is like and how people are sleeping, the dose that people get into their eyes might be very hard to predict from something that could be regulated, such as public lighting.

Still to be established systematically is the link between outdoor illumination at night and what someone's corneal dose might be. Bearing in mind that we also have the effects of daytime light exposure, for example, which might make us less sensitive to evening light, it becomes quite complicated to make a simple prediction. More research needs to be done. Fundamentally, research that could establish links between something that can be regulated and something that cannot—namely, corneal light exposure—is a key priority.

When we think about hospital environments, ICUs, care homes and similar places, which might be illuminated at night, there is a much wider opportunity to directly predict what light actually enters someone's eye. Generally speaking, light pollution is a term that is variably defined. It really depends on the source, where it is and how people are positioned in front of it. There are opportunities, but one would have to think carefully about whether street lighting, for example, is the right locus for such regulation to prevent artificial light at night having negative effects.

Professor Shantha Rajaratnam: I agree with Professor Spitschan that the first step is to disseminate the new measurement system for lighting. We know that the current measurement systems are not appropriate for capturing the potential health effects for humans. The first thing is to prescribe standards for how lighting designers and so on should quantify and spatially model the light characteristics of new spaces that are designed. Of particularly high priority are the ones that Professor Spitschan mentioned, where people live in those facilities day and night. I would also add office environments and so on.

We have been talking about light at night and light pollution, but we also know that light has many positive effects during the daytime. The first step in regulating this space is to look at disseminating light metrics that are relevant to human health and ensuring that those are the ones captured in design standards.

I am happy to share with the committee a recent review on outdoor lighting which looked at a number of national and regional jurisdictions with legislation and guidelines related to outdoor artificial lighting at night. The report concluded that only two jurisdictions—I believe it was Croatia and Seoul—have outdoor lighting standards that have been developed specifically to protect human health, or with that in mind in addition to other ecological considerations such as energy consumption and so on.

Baroness Neville-Jones: Did those jurisdictions regulate the devices, or the total effect?

Professor Shantha Rajaratnam: No. Looking at the paper itself, in Croatia, for example, there are restrictions on the colour of outdoor lighting and the relevant colour temperature, et cetera, in order to minimise the impact on human health. It did not relate to indoor lighting, device use or anything like that.

Baroness Neville-Jones: And it was related to health, and not to cosmetic considerations or glare.

Professor Shantha Rajaratnam: In that jurisdiction, I believe it was about energy consumption, health and the natural ecosystem.

Baroness Neville-Jones: It seems to me that implicit in our conversation all the way through is the question of too much light. We have not talked about whether there are occasions when we ought to ensure that there is enough light.

Professor Shantha Rajaratnam: Professor Spitschan talked about illuminance recommendations that included optimal daytime lighting. Is that right, Professor Spitschan? Do you want to repeat that?

Professor Dr Manuel Spitschan: The recommendations suggest a minimum amount of melanopic illuminance that one should get during the day. It is a relatively low number, 250 lux. If you go outside in bright daylight you will get much more than that. Ultimately, if the question is about optimising daytime light exposure, which we know has positive effects—modulation of alertness, making us potentially less sensitive to

evening light disruption—there is a lot of scope, in particular in offices, to improve and increase that.

Baroness Neville-Jones: And in classrooms.

Professor Dr Manuel Spitschan: And in classrooms, of course. There are plenty of indoor lighting scenarios in which this could be made brighter. Of course, the current standards look at illuminance for tasks. Building regulations—lighting regulations—set minimum standards that are really for how optimal lighting should be for you to perform a fine spatial task or how bright it should be for you to perform well. They have yet to incorporate these newly described and characterised melanopic, circadian and neuroendocrine effects of light.

Dr Christopher Kyba: We have been talking very much about the non-visual effects of light, but of course for outdoor light especially we employ it for visual reasons. So there are places where regulation makes sense. There is often a competition as to who can make gas station canopy lighting brighter, for example. However, you leave the gas station and then drive on to the street, and when the lighting under a gas station canopy goes up to 250, 750 or 1,000 lux, which has occurred, and then go on to a street that is one-fiftieth as bright, that presents a potential danger, particularly for older drivers, and for the pedestrians and cyclists who are using the street or in conflict zones.

Similarly, when you have a video display that is made to be visible during the daytime and the person who is operating it does not dim it at night-time or does not dim it enough, those signs can in many cases cause significant amounts of glare, which could introduce a tripping hazard for pedestrians or make it more difficult for drivers to see someone. It is in my opinion therefore entirely justifiable to consider limitations on the maximum radiance or illuminance of things like signs, or the illuminance that is allowed under gas station canopies, on the grounds of public safety and trying to create a homogenous visual environment that is easier for people to deal with at night-time.

Similarly, to come back to the first question on regulations, in Germany a limit of 1 lux is allowed on windows, which is based on an annoyance law that has been on the books for a long time, not on health effects.

Baroness Neville-Jones: We have not discussed the difference between people's attitudes and their level of toleration as distinct from any effect on health.

The Chair: We have to move on, unfortunately.

Q24

Lord Rees of Ludlow: The last detailed report from the UK Parliament on issues of light pollution was 2009. Since then, cheap LED lighting has become more widespread. Has this made light pollution substantially worse compared to the intensity and the spectrum of the incandescent lighting that we had before? This question has been partly answered, but I wonder whether Professor Kyba has further thoughts on this.

Dr Christopher Kyba: This goes a bit beyond human health but is very much related. We see that the number of stars that people report they

are able to see has dramatically decreased since 2011, which coincides with LEDs becoming a much larger proportion of the market share for outdoor lighting. We also see in satellite data that most places are becoming brighter. Interestingly enough, the satellite data indicate that many places in the UK are becoming darker, although the explanation for that is not clear yet.

Most countries and lit areas are becoming brighter, and in all the history of human development of lighting technology, going from oil to gas to electric arc lighting and incandescent lighting, vapour discharge and now LEDs, every time we have improved the luminous efficacy of lights, people have responded by making more light. That does not mean that LEDs in particular are necessarily bad; a lot of amazing things can be done with LEDs, such as using half-watt or quarter-watt LEDs to very gently illuminate parking areas or tripping hazards in a more natural environment.

To a large extent, those advantages have not been explored yet. We tend to take the pole that existed for a high-pressure sodium lamp—we do not want to spend money on putting up a new pole and doing construction on the ground, so we put an LED up there—but the existing pole and spacing is not well suited to LED streetlights. In many cases, this practice results in either a dark patch in between the lights or a great deal of glare. So yes, this adaptation of the technology has very likely made the total amount of light in the environment greater, particularly in the outdoor environment, but it has introduced some issues with glare that are now more problematic than before.

What has not been mentioned so far today is flicker, which is an issue for a lot of individuals—again, not everybody, but some are very sensitive to it. This can be an issue especially with some of the older lighting types as they age, but many poorly designed LED drivers also introduce a great deal of flicker into the environment, which for some individuals can be very problematic.

Q25 Lord Rees of Ludlow: Is the effect of very bright lights—headlights that can dazzle people—the same as moving away from a garage, which you mentioned? Do you think that is a health or a safety hazard?

Dr Christopher Kyba: It is a safety question. There is very little discussion between the people who create headlights and the people who create street lighting. A paper came out just in the last two weeks that suggested that in many cases headlights can worsen the contrast of objects on the street. Basically, you want either a positive contrast of, say, a pedestrian against a dark road, or to have a situation where you have negative contrast, for example a person in dark clothing seen against a road lit by street lighting, in order to see them. Unfortunately, it is possible to create a situation where the headlights and the streetlighting work together to lower contrast by making the person or object and road have the same luminance.

It is very difficult to come up immediately with a solution to that. The suggestion from the authors of the paper was that headlights should be

dimmer in urban environments. Thinking very far forward, we do not actually need street lighting—we do not need to light streets. We need lighting for humans. Thinking about how to move beyond the way we have lit in the past for automobiles and switching into thinking about how we light for human beings and the roadway users, and light these conflict zones, there may be an opportunity to improve that in the long-distant future.

Lord Rees of Ludlow: Thank you very much. That was very comprehensive. Would the other two panellists like to add to that or say anything about foreseeable developments in the future that might affect policy-makers?

Professor Shantha Rajaratnam: LED lighting has created tremendous opportunity for us to be able to systematically create light sources for particular purposes. For example, we can develop light sources that are enriched in particular wavelengths, depleted in particular wavelengths, or that change dynamically. We have tremendous opportunity. Are we utilising that opportunity at the moment?

My feeling is: probably not. I have gone into many indoor environments—for example, hospitals—and looked at the LED lighting that is used, and it is pretty random at the moment. You have lighting that is enriched in short wavelengths, sometimes in an environment where it should not be, and lighting that is depleted—the cool and the warm lighting are in the wrong places. This is why it is critical that the new measures that are relevant to human health are disseminated quickly. LED lighting is being rapidly installed and deployed in indoor environments but in a haphazard way that can cause harm, rather than us seizing the opportunity that is created.

Professor Dr Manuel Spitschan: I would reinforce one point that has just made about tuneable lighting. We have a great opportunity to adapt dynamically to different scenarios. In this area, there are studies that have examined the impact of dynamic lighting schedules in ICUs, and some laboratory studies. But we still lack a broad evidence base to say that a specific lighting schedule is appropriate to support specific health functions.

Q26 **Lord Wei:** We are all too aware that the answer to many of our questions is that we need to do more research. In making such a recommendation to the Government, we need to be specific. If you had funding, what kind of studies do you think would be the most important to undertake? In which areas do we lack evidence that could have a real impact on policy?

Dr Christopher Kyba: One area I can think of is not one that I could study personally, because I am physicist and not a health researcher. However, I feel that very little work has been done on the potential physiological impacts of light that are related to the visual pathway but not directly to vision. For example, I am often alerted and woken up by the moon if I am in a place where moonlight happens to shine in my face. That cannot be explained through melatonin suppression. Similarly, what

is the alerting mechanism that tends to wake people up in their beds in the morning from twilight shining through their eyelids?

I may have just missed it, but I have seen very little work done on that. It may connect to the issue of why some people say that they are so disturbed by small sources of light in their environment. I would recommend focusing on people who claim to experience a strong effect; that subset of the population may be much more sensitive than the average person.

Professor Shantha Rajaratnam: That is a wonderful question. There are a number of areas where there is an opportunity for significant research and evidence-gathering. One is an area that we talked about earlier: children and adolescents. We recognise that there is an urgent societal need to curb the rise in adolescent mental health conditions. The onset of these conditions often manifests in those years, and sleep and circadian rhythms offer us a unique opportunity to intervene and prevent. There is an urgent need to understand the contribution of artificial lighting in exacerbating those risk factors.

The second area is in the working population. A group that is particularly vulnerable to circadian rhythm disruption due to light exposure is shift workers. This is a group of the population that is growing in urban economies, and it is likely to continue to rise post pandemic, with flexible working arrangements and so on. How do we protect the circadian health and overall health of that group of individuals with very variable sleep schedules and therefore light exposure schedules? There is an urgent need for studies in that area.

The third area I would look at is in the ageing population. In many of our populations we are observing a rise in cognitive decline, dementias and neurodegenerative disorders. Again, we know that the circadian system is involved and implicated in a number of those neurodegenerative conditions. There is an urgent need to understand the contribution of light exposure and the opportunity to improve light environments. We know from a number of intervention studies that have been done already that there is a real opportunity here to delay the progression of neurodegeneration as well.

Those are three particularly vulnerable populations. To return to the original point we made at the start, it would be very powerful now—knowing that we understand the circadian system's fundamental properties in its response to light—to do a cohort study measuring the right things in order to understand the health risk factors. With the kinds of instrumentation that are now readily available to us, we can quickly accumulate and understand which are the important variables that need to be regulated and brought into policy recommendations. That would be the fourth area, at a population level: collecting large-scale data with the right light metrics, as well as rigorous health data.

Professor Dr Manuel Spitschan: I see two big areas that require a lot more research. The first is understanding the real-world light exposures that people get and the associated health outcomes, which is similar to the cohort study that was just described. I would highlight a point that

has not been mentioned: the socioeconomic disparities that might exist in the provision of light exposure and lighting technology. We know that in sleep and circadian health there are quite strong sleep health disparities. That must be looked at at a broad population level.

The second area, or the second way forward, is looking at light exposure as something of a self-selective behaviour. Rather than trying to find technological solutions to circadian disruption, another parallel approach might be to ask how we get people to make the right decisions about how they expose themselves to light. That is a much more person-centred but none the less important behavioural approach to supporting human health with good light.

Lord Winston: There is one very big public health problem that you have not mentioned, and I wonder if we could dwell on that for a second. There must be at least 3 million people in Britain who have reproductive disorders, on which a huge amount of money is spent. We know from animal studies that light makes a very big difference to reproduction. What research is being done on the diseases of human reproduction, particularly miscarriage and infertility?

Professor Shantha Rajaratnam: Very briefly, where there have been cohort studies of shift workers looking at circadian disruption and its relationship with reproductive disturbances, clear links and associations have been drawn. In animal models, we know that disruption of the photoperiod—that is, the length of the day—and so on causes significant changes in reproductive parameters. So there is every reason to expect that disruption of the circadian system could be one of the contributing factors in that line of evidence.

Professor Dr Manuel Spitschan: I would add that we have evidence to believe that there are such links in this area, but I do not think it has been systematically explored to the extent that it should be.

The Chair: I will have to draw this session to a close now, but I reiterate our thanks to our three witnesses. You have raised some very interesting points; we have had a lot of nodding heads at various times.