CHAPTER 12

Work Environmental Factors

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THIS CHAPTER PROVIDES:

- A brief introduction to the occupational hygiene discipline.
- Descriptions of environmental aspects in physics terms.
- Descriptions of how environmental aspects affect the human physiologically, cognitively and psychologically.
- Descriptions of how environmental aspects can be measured.

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WHY DO I NEED TO KNOW THIS AS AN ENGINEER?

As you learned in Chapter 3, the human body has certain responses to physical loading. It might not be obvious at first, but many environmental aspects of our work environment can cause mental, psychological and physical loading on the body, especially in extreme work environments. When the body is reacting to stimuli from the environment, or has to work while wearing protective clothing and gear, it often puts us in a slightly weaker position to take on physical and mental loading from the actual work tasks. As a result, environmental aspects can be anything from annoying to distracting to hazardous and completely debilitating. As engineers, we can use our basic understanding of physics and measurement to assess different environmental factors. Usually, we make a present state analysis of the environment and compare it to ideal measurements for human performance, in order to establish criteria for a change. The specific discipline of evaluating work environmental factors is also known as *occupational (or industrial) hygiene*, and has its own professional organizations worldwide. This discipline tends to cover many additional environmental factors, so in this book we focus primarily on five types of work environmental factors that can affect cognitive performance, physical loading on the body or health and safety in general: thermal climate, lighting, sound, vibration and radiation.

Creating a suitable balance of these factors is part of designing a well functioning workplace. Understanding these factors, the ways that the human body reacts to them, and how to use instruments, standards and methods to evaluate their suitability, are all essential skills in the workplace engineering toolbox.

WHICH ROLES BENEFIT FROM THIS KNOWLEDGE?

The *system performance improver* can use the knowledge in this chapter to ensure that the working conditions that are not directly part of workplace and equipment design may still be accounted for in the furnishing of work spaces, the planning of work tasks, limiting exposure to particular environments and by supplying protective gear. Many standards for making the environmental factors exist, some of which can be used as helpful design guidelines. The *work environment/safety specialist* benefits from being able to point out standardized limit values for exposure to specific environmental conditions. These established standards can be a big help in backing up arguments of how to protect workers when the work demands particular conditions. Also, understanding the direct impacts of environmental exposure on human physiology and cognition can help in the process of suggesting solutions for how to target risks. The *sustainability agent,* who may be tasked with addressing environmental sustainability also, may benefit from understanding how certain energy-consuming work conditions (for example keeping a space heated or cooled) can be reasoned about in conjunction with human well-being goals – at best, this role can pursue solutions that have beneficial impacts on all sustainability aspects.

12.1. The human body in different environments

As you have learned before, the human body has abilities and limitations that need to be considered in the design of work environments. For example: in cold conditions, blood flow to the outer extremities is restricted, which may lead to shivering that can impair the sense of touch and hinder precision work. In a loud, noisy environment, cognitive resources are split between listening for information and hearing non-meaningful noise, which can impair concentration and cause psychological stress. In dim light, it is a common occurrence that people need to bend closer to see what they are doing, causing poor ergonomics. In a vibrating environment, internal muscular loading increases because the body is reacting to the small forces propagating throughout its tissues, leading to fatigue. All of these examples illustrate that the physical work environment has a great influence on human well-being and system performance.

To design the optimal conditions to perform work, we need to be aware of the "comfort zones" in which the human body can best perform both mentally and physically, without wasting resources on extra loading from the environment. For this reason, knowledge of measures, tools and ideal limit values are of great value when designing a work environment.

12.2. Occupational (or Industrial) Hygiene

Since workplace improvement is not solely the concern of ergonomists, there is also a well-known discipline in its own right that focuses on work environmental factors, and to some extent its scope overlaps greatly with that of this book. This discipline is known as Occupational Hygiene (or in North America, Industrial Hygiene). We offer a quick introduction here to orient our reader to the discipline. The International Occupational Hygiene Association (IOHA) defines occupational hygiene as:

> "the discipline of anticipating, recognizing, evaluating and controlling *health* hazards in the working environment with the objective of protecting worker health and well-being and safeguarding the community at large."
>
> (IOHA, n.d)

Occupational/industrial hygienists concern themselves with many of the same aspects that ergonomists and production engineers do, but may come from a different educational background (quite often in engineering, chemistry, physics, or a biological or physical science), which places a more pronounced emphasis on assessing work-environmental concerns with a scientific measure-and-control approach. Some examples include:

- Indoor air quality, air contaminants
- Chemical exposure hazards, e.g. lead
- Emergency response planning and community right-to-know
- Occupational diseases (AIDS in the workplace, tuberculosis, silicosis)
- Biological hazards, e.g. bacteria, viruses, fungi
- Potentially hazardous agents such as asbestos, pesticides, and radon gas
- Ergonomic hazards, cumulative trauma disorders (repetitive stress injuries, carpal tunnel syndrome)
- Radiation (electromagnetic fields, microwaves)
- Reproductive health hazards in the workplace
- Exposure limits to chemical and physical agents
- Detection and control of potential occupational hazards such as noise, radiation, and illumination
- Hazardous waste management

(OSHA, n.d.; American Industrial Hygiene Association, 2016)

The discipline also features a well-accepted "Hierarchy of Controls" (NIOSH, 2015) according to the American National Standards institute (2005), which describes in which order any found health hazards are to be controlled. Primarily (for best control effectiveness and business value), the hazard should be eliminated, but if this is not possible, the order of preferable interventions is substitution (replacing the hazard); engineering controls (isolating workers from the hazard); administrative controls (changing how people work); and finally as a last resort, providing workers personal protective equipment. Figure 12.1 shows this hierarchy. This prioritization approach is used by occupational/industrial hygienists for all kinds of identified workplace hazards, including physical ergonomics and psychosocial aspects.

In this book we will not elaborate on all the physical and chemical hazards of industrial workplaces, as the subject is extensive in its own right and may vary in scope depending on the exact industrial sector being studied – for example, some work environments that are dusty or humid may have air quality as a major concern, while others may involve continuous exposure to chemicals, sprays, etc., and may require other approaches. However, there are many knowledge resources to turn to in the form of associations and professional organizations concerning themselves with occupational/industrial hygiene, e.g. the Occupational Safety and Health Administration (OSHA) of the United States Department of Labor; the International Occupational Hygiene Association (IOHA); the American Industrial Hygiene Association (AIHA), and many more. These organizations provide training, conferences, knowledge resources and a community of science and practice regarding workplace hazard identification. In the following sections, we will focus mainly on the work environmental factors known as *physical hazards* (OSHA, n.d.).

12.3. Thermal climate

Thermal climate is more than just temperature. The predominant impression of climate usually has to do with feeling too hot, too cold, or just right (which often corresponds to not noticing the climate at

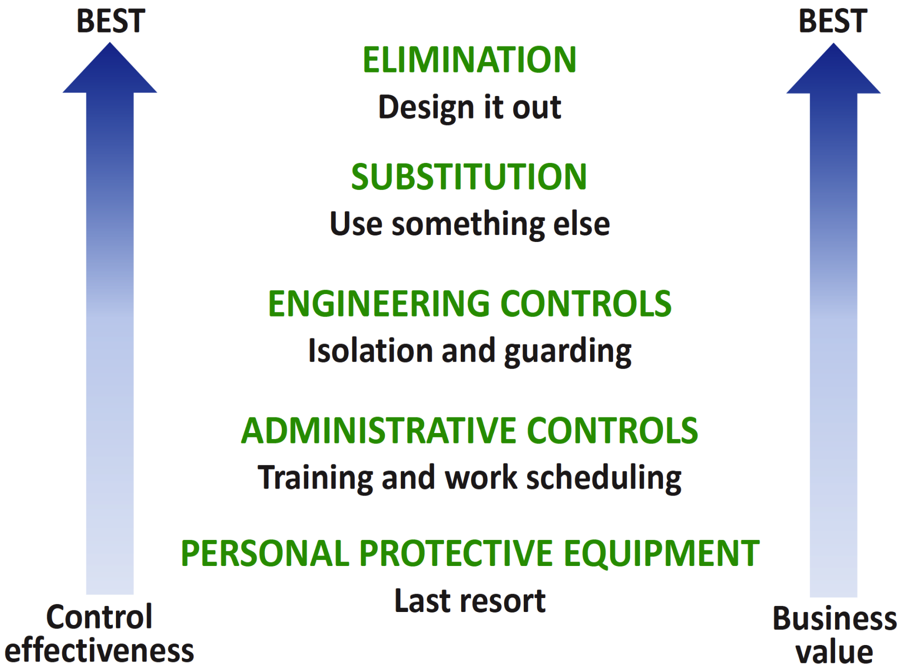

Figure 12.1: The Hierarchy of Controls against occupational hazards; image from NIOSH (2013 p. 48). Image reproduced with permission from CDC/NIOSH. Image is in the public domain via www.cdc.gov.

all). The ideal thermal climate is known as comfort climate, which is the often-unnoticed psychophysical state in which humans experience satisfaction with the climate, and thereby the best conditions for work. However, the human experience of temperature is affected by other factors, like air speed, humidity and our ability to exchange heat with the environment. Therefore, climate is a complex environmental factor that can be assessed by studying the following climate parameters: heat, cold, comfort climate, heat exchange, clothes and insulation.

Thermal balance

A healthy human body automatically regulates thermal exchange with its surroundings in order to keep the temperature of the blood constant. If the blood temperature changes, the body is rapidly put into a state of discomfort and illness, often resulting in compensation behaviours, or in worst cases, impairing mental or physical performance.

The balance of the body's heat exchange with the environment can be expressed in terms of power (energy consumed per time unit, i.e. Joules/second = Watt). The balance in the following equation (Bohgard, 2009 p. 198) states that the *difference* (usually an increase) in power produced by the body and the power generated by the mechanical work must be balanced by a number of heat/energy losses of different kinds:

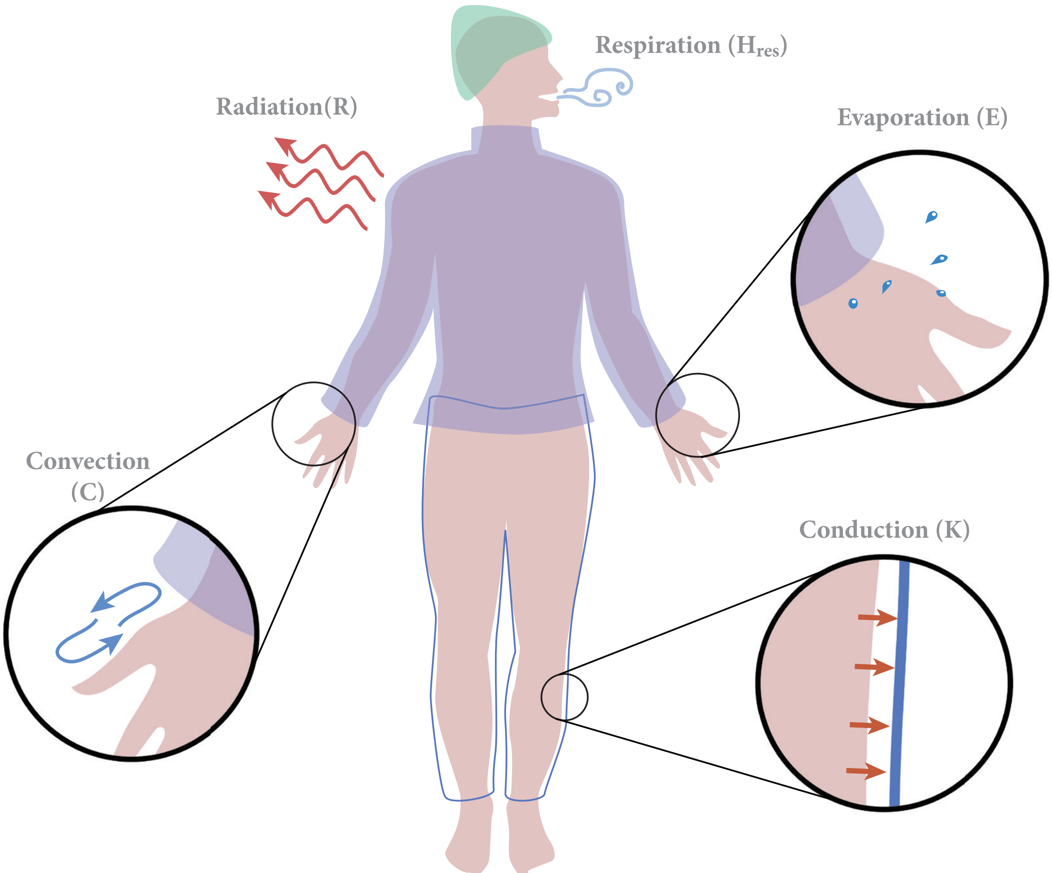

Figure 12.2: The different components of thermal power loss. Due to the thermal inertia of most clothing materials, conduction is presumably negligible regarding the contact of the clothing to the skin.

Illustration by C. Berlin.

$$\mathbf{M - W = R + C + K + E + H_{res}}$$

Where:

M = power produced in the body
W = mechanical power
R = power loss by heat radiation
C = power loss by convection
K = power loss by conduction
E = power loss by evaporation from body surface
H_{res} = (as in <u>res</u>piration) power loss by evaporation from airways

When the above equation is not in equilibrium, the result is a rise or fall of the body's temperature, often leading to discomfort and possibly higher injury risk and performance impairment. Symptoms of this imbalance often come in the form of complaints or physical manifestations, e.g. irritation, dryness, rashes, tiredness, headaches or muscular tension.

In different external temperatures, the components of heat exchange (Fig. 11.1) are proportioned differently. For example, in hot environments, it is likely that much heat transfer will be due to evaporation (sweating) and respiratory evaporation, while in a cold climate, the dominant components will instead be radiation and convection (air circulation, absorbed by clothing). The body compensates for extreme climates by regulating its own production of heat; for example, this is why we shiver in cold temperatures, activating heat in our muscles.

For reference, Table 12.1 shows the power outputs for a "standard person" measuring 175 cm (corresponding to a surface area of 1.84 m^2) and weighing 70 kg:

Table 12.1: Metabolic rate (power output over surface area) for different activities (adapted from Bohgard, 2009 p.197) for a person measuring 175 cm (corresponding to a surface area of 1.84 m^2) and weighing 70 kg.

Activity	***Metabolic rate (W/m²) (based on ISO 8996 and ISO/TS 16976-1)***
Rest	65
Light work	100
Moderately heavy work	165
Heavy work	230
Maximum	600

12.4. Thermal exposure risks

One thing worth mentioning is that a hot or cold environment also changes the temperature of materials, which can add to the physical and mental stress of performing assembly work since the hands are extra sensitive to heat and cold. This is especially true for metals, both in the form of tools and product material.

In very warm environments, exposure of the skin to a hot surface for certain duration of time may result in a burn, which is a painful, irreversible tissue injury. Depending on the temperature of the material that the skin is exposed to, we can tolerate different time durations of exposure up to the threshold of pain or the threshold of injury. The reason for the "delay" of the burn is due to thermal inertia, a property that describes the speed of the heat transfer between the material and the skin, and is dependent on the kind of material, the size of the contact point, surface characteristics, conductivity and other factors. For example, the thermal inertia of a piece of metal allows a much more rapid heat transfer to the skin, compared to a similar-sized piece of wood at the same temperature. This phenomenon happens on both extremes of the scale; in very cold temperatures, exposure to very cold materials or air for certain duration of time can lead to irreversible tissue damages in the form of frostbite.

12.5. Heat

The sensation of heat is experienced when the body senses its surroundings (air, water or material objects, usually via the skin) as being warmer than the body itself. Table 12.2 shows how heat at different levels can have the following effects:

Table 12.2: Effects of heat at different intensities.

Warm, within comfort zone	• Increased peripheral blood flow, widened blood vessels • Skin temperature rises • Drop in muscle tension
Moderate heat, just slightly beyond comfort zone	• Sweating • Loss of fluids and salt • Tiredness • Increased hostility • Decreased performance and alertness • Increased risk for mistakes and errors • Increased risk for accidents
Extreme heat, discomfort	• Painful cramps • Impaired function of stomach and intestines • Heat regulation failure

12.6. Cold

In cold environments, the human body is especially sensitive to the external climate due to additional factors that may alter the sensation of temperature. Wind chill temperature (twc) captures this by taking consideration of the nominal temperature and the effects of wind velocity. Many times, air velocity can increase the local skin sensation of the air temperature being colder than its nominal measurement, which can lead to increased risk for severe cold-related damages (see Table 12.3) at shorter time exposures. (This also refers back to the previous description of burn risk as a function of exposure time to materials at different temperatures.)

Table 12.3: Effects of cold at different intensities.

Cool, within comfort zone	• Reduction of blood flow to skin, constricted blood vessels • Decrease in performance due to thick clothing
Moderate cold, just slightly beyond comfort zone	• Discomfort • Shivering • Decreased fine motor function • Decrease in sense of touch
Extreme cold, discomfort	• Disorientation • Apathy • Weaker breathing • Frostbite: oxygen shortage to a part of the body resulting in tissue damage

12.7. Assessing climate

We can measure thermal climate in a number of ways. In order to design work environments that have satisfactory thermal climate, we need to consider all the influencing factors that lead to a human response:

- air temperature
- radiation
- air humidity
- air velocity
- clothing
- activity

The International Organization for Standardization – ISO – specifies several procedures for assessing climate, some of which are specialized for hot or cold environments and specific industrial applications (Figure 12.3). This chapter will bring up two of these: one objective parameter measurement called Wet Bulb Globe Temperature (WBGT, ISO 7243) and one subjective measurement of thermal comfort, called Predicted Mean Value/ Predicted Percentage of Dissatisfied (ISO 7730:2005).

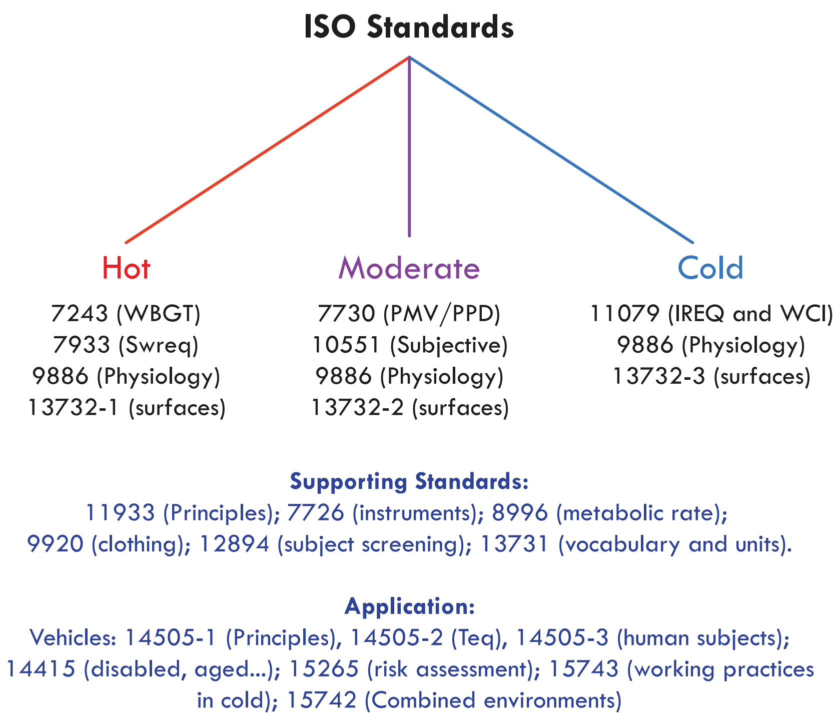

Figure 12.3: ISO standard methods for different aspects of climate parameters (based on Figure 1 from Parsons, 2006; p. 370).

Image by C. Berlin.

Figure 12.4: Equipment for measuring WBGT being used in the field by a U.S. Navy seaman.
U.S. Navy photo by Gary Nichols / Released. The image is in the public domain via www.navy.mil.

Climate parameters (objective)

A known tool for measuring climate parameters in non-comfort climates is the "Wet Bulb Globe Thermometer", which measures the "Wet Bulb Globe Temperature Index" (WBGT) as defined by the Heat Stress standard ISO 7243 (Parsons, 2006). The WBGT is measured with:

- A sensor that measures the air temperature (thermometer), shielded from radiation.
- A cylindrical natural wet bulb sensor that measures the temperature under the influence of humidity, covered by a sleeve of wet cotton material.
- A standardized thin, matte, 150mm-wide black globe at whose centre we measure the globe temperature, which measures the impact of radiation on temperature.

These different components (Figure 12.4) allow us to take consideration of wind chill and radiation factors, as well as the air temperature. Different coefficients are used to combine the measurements into the WBGT, depending on whether the measurement is taken indoors or outdoors (since outdoor environments have different radiation and wind chill factors to take consideration of).

Indoors: $WBGT= 0.7t_{nw}+0.3t_{g}$
Outside buildings (with solar load): $WBGT= 0.7t_{nw}+0.2t_{g}+0.1t_{a}$

Where:
t_{nw}: natural wet bulb temperature
t_g: globe temperature
t_a: air temperature

The measured WBGT is compared to a reference value determined by the ISO standard as suitable for the studied activity. The reference value is set so that there is no risk that the body temperature is altered as a result of the activity being performed in that temperature. The standard also states limit values for different durations of activity (Parsons, 2006).

Thermal comfort (subjective)

The standard ISO 7730:2005 describes a way to assess how many people in a population will be satisfied with the temperature at a workplace. The standard applies to healthy men and women in moderate indoor thermal climates, so adjustments must be made for sick people as they may perceive the thermal climate differently. This is a two-step method that takes consideration of a) activity and thermal load (the Predicted Mean Vote, PMV), and b) the proportion of a group of people who will find the temperature too warm or too cold (the Predicted Percentage of Dissatisfied, PPD).

The PPD is calculated as a function of the PMV, so these calculations go together. According to the standard ISO 7730:2005, "The PMV is an index that predicts the mean value of the votes of a large group of persons on the seven-point thermal sensation scale" (ISO 7730:2005 p. 2) which is shown in Figure 12.5.

The PMV is based on studies of people being exposed to different temperatures and then assessing their opinion of the climate on the scale in Figure 12.5. The calculation of PMV is a rather complicated one that takes "metabolic rate, clothing insulation, air temperature, radiant temperature, air velocity

+ 3	Hot
+ 2	Warm
+ 1	Slightly warm
0	Neutral
– 1	Slightly cool
–2	Cool
– 3	Cold

Figure 12.5: The PMV index Thermal Sensation Scale (from ISO 7730:2005).
Image reproduced with permission from SIS (Swedish Standards Institute).

and air humidity" into account (the detailed equation is in ISO 7730:2005 p.3). In its simplest form, the equation for PMV looks like this:

$$\mathbf{PMV = (0.303^{*}\ e^{-0.036M} + 0.028)L}$$

Where M = Activity and L = Thermal load.

Once the PMV is obtained, the PPD can be calculated to estimate the expected number of people who will find the temperature to warm or too cold (predicted percentage of dissatisfied).

$$\mathbf{PPD = 100 - 95^{*}e^{[-(0.03353^{*}PMV4+\ 0.2179^{*}\ PMV2)]}}$$

Since it is unlikely (due to variations in personal preference) that a majority of the population will be satisfied with the climate (corresponding to a PMV value of 0), the PPD chart frequently shows a U-shaped curve as shown in Figure 12.6.

A rule of thumb is that suitable indoor climate is achieved when -0, 5 < PMV < 0, 5 and the PPD is less than 10%.

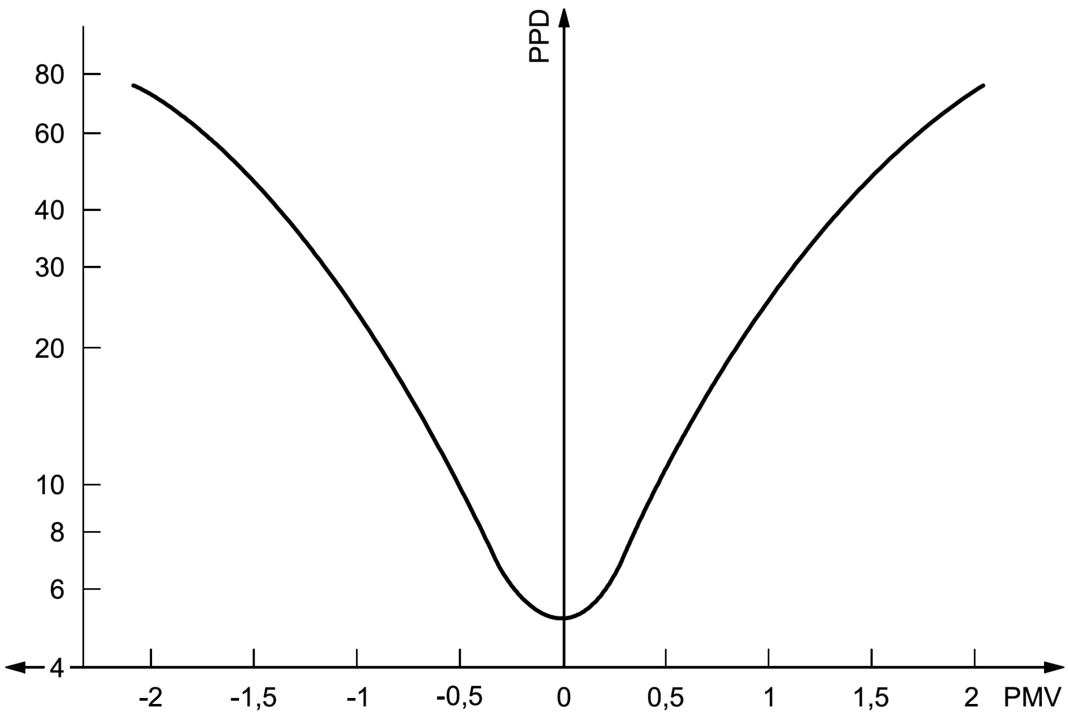

Figure 12.6: Usual appearance of a PPD chart as a function of PMV (ISO 7730:2005).
Image reproduced with permission from SIS (Swedish Standards Institute).

12.8. Clothing

Changing clothing changes the human's ability to exchange heat with the environment. The insulating properties of different types and amounts of clothing has a definite effect on our ability to work in different climates, due to their ability to limit heat exchange due to radiation and convection, and their interference with evaporation. The insulating capacity is measured in terms of *clo*, a unit of insulation defined in the standard ISO 7730:2005 (Figure 12.6). It is close in magnitude to the R value, an measure used to describe the insulation of housing (thermal resistance), for a particular material or

Garment	I_{clu} clo	I_{clu} $m^2 \cdot K/W$
Underwear		
Panties	0,03	0,005
Underpants with long legs	0,10	0,016
Singlet	0,04	0,006
T-shirt	0,09	0,014
Shirt with long sleeves	0,12	0,019
Panties and bra	0,03	0,005
Shirts/Blouses		
Short sleeves	0,15	0,023
Light-weight, long sleeves	0,20	0,031
Normal, long sleeves	0,25	0,039
Flannel shirt, long sleeves	0,30	0,047
Light-weight blouse, long sleeves	0,15	0,023
Trousers		
Shorts	0,06	0,009
(...)		
High-insulative, fibre-pelt		
Boiler suit	0,90	0,140
Trousers	0,35	0,054
Jacket	0,40	0,062
Vest	0,20	0,031
Outdoor clothing		
Coat	0,60	0,093
Down jacket	0,55	0,085
Parka	0,70	0,109
Fibre-pelt overalls	0,55	0,085
Sundries		
Socks	0,02	0,003
Thick, ankle socks	0,05	0,008

Figure 12.7: Selected values of thermal insulation (in clo), excerpted from table C.2 in the standard ISO 7730:2005.

combination of materials. 1 clo corresponds to 0,155 m^2 K/W (pronounced “metres squared Kelvin per Watt”) and varies between 0 to 3 clo. For reference, a person dressed in 0 clo is naked, while a 3-clo outfit is suitable for someone who is going skiing.

The amount of insulation that allows a human (at rest, and in an environment at 21°C room temperature and 0.1 m/s air velocity) to remain in thermal equilibrium (i.e. no sweating, freezing or change in body temperature) is 1 clo, thanks to the combination of the clothing insulation and the body’s heat exchange processes.

12.9. Lighting

Sight and the visible spectrum

Sight is one of the most dominant senses, controlling around 90% of our daily activities (Kroemer, 1997). Our eyes are constantly supplying us with information through visible light. So to ensure the correct information is supplied, lighting is a key consideration in the design of workplaces. Essentially, light is a form of electromagnetic radiation, and the visible spectrum is a portion of the electromagnetic spectrum that can be identified by the human eye, due to its wavelength (Figure 12.8). A typical human eye will respond to wavelengths from about 390 to 700 nm (Starr, 2005).

The process of interpreting an environment through visible light by the brain is called visual perception, and the outcome of this process is known as sight or vision. How we see an object is a combination of light, the object being perceived, the eye and perception. Rays of light from an object or the environment pass through the pupil of the eye and meet at the retina. The light energy is then converted to bioelectric energy, which stimulates the optic nerve to the brain. After a series of impulses and various filtering processes, all the signals are integrated into a representation of the external environment in the brain’s cerebral cortex.

While an in-depth understanding of the complex interaction between the eye and the brain during visual perception is outside the scope of this book, an understanding of the different characteristics of light and how to measure them supports the design of healthy workplaces. Studies have shown the impact lighting can have on workplace productivity, with reductions in rejected products and accidents. One such study in an American factory demonstrated a 5% production increase when illumination was increased, combining this productivity increase with the reduced amount of waste resulting from enhanced lighting, cost savings of 24% were achieved (Kroemer, 1997).

12.10. Photometry

This discipline, which deals with the measurement of visible light as perceived by human eyes, is known as photometry (Bass, 1995). There are many different lighting characteristics within the field of photometry, but in terms of ergonomics and workplace design, the three main lighting measurements of interest are:

- Luminous intensity
- Illuminance
- Luminance

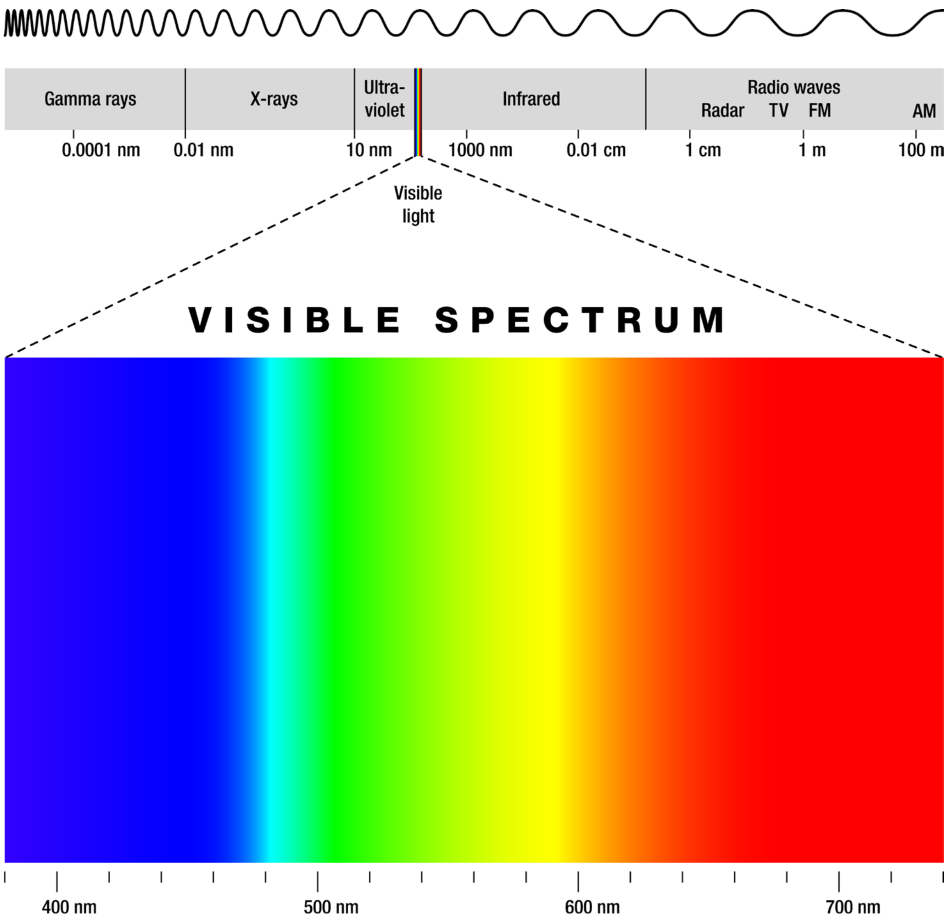

Figure 12.8: Visible spectrum.

Luminous intensity

Luminous intensity is the quantity of visible light that is emitted in unit time per unit solid angle. Historically luminous intensity was measured in terms of the visible radiation emitted by a candle flame, which lead to the name of its measurement unit Candela (cd). Nowadays, 1 cd is defined as 1/683 W/sr at the frequency of 540 x 10^{12}Hz (Bohgard, 2009).

Illuminance

Illuminance quantifies how well a surface is lit; the light could come from either the sun or artificial light sources. Illuminance is measured in lux and can vary considerably as seen in Table 12.4.

Table 12.4: Outdoor illumination values.

Condition	*Illumination (lux)*
Sunlight	100,000
Full Daylight	10,000
Overcast Day	1000
Very Dark Day	100
Twilight	1
Full Moon	.1
Quarter Moon	.01
Starlight	.001
Overcast Night	.0001

Luminance

Luminance is the amount of light reflected or emitted from a surface, essentially a measurement of the light power that reaches the human eye, measured in candela per m^2 (Cd/m^2) (Kroemer, 1995; Bohgard, 2009). Excessive luminance in the workplace should be avoided.

12.11. Measuring light parameters

To ensure lighting in the work environment meets standards and recommended guidelines various measuring instruments can be used. Both lux meters and luminance meters use a photo detector to measure illuminance and luminance.

Additional light parameters

In addition to the three photometric quantities we have already introduced, it is also important to consider glare, reflections, contrast and viewing distance when designing workplaces.

Glare

Glare is a visual sensation in which excessive overexposed light impairs vision. In some cases it can impair vision completely, while in other cases it is just deemed uncomfortable and irritating. Glare can occur in four different ways:

- **Direct Glare:** When the light source is so bright the eye can't adjust, so vision is inhibited.
- **Indirect Glare:** When the light source is reflected on shiny surfaces, inhibiting vision.
- **Contrast Glare:** When a significant difference in luminance levels inhibits vision.

- **Adaptation Glare:** When vision is inhibited due to sudden changes between light and dark environments.

Reflections

Reflectance concerns the ability of a surface to reflect light, and is expressed as a percentage (%) of reflected light compared to incident light:

$$\text{Reflectance (\%)} = \frac{\text{Luminance}}{\text{Illuminance}} \times 100$$

Different materials absorb and reflect different amounts of light. Generally in the work environment the walls and ceilings are lightly coloured to enable light to reflect around the room. Equipment and machinery on the other hand, tends to be darker in colour with a matte finish to limit disruptive light reflections.

Contrast

$$\text{Contrast} = \frac{\text{Luminance of object} - \text{Luminance of background}}{\text{Luminance of background}}$$

Contrast is the difference in luminance between two surfaces; this relationship can be described as the brightness of an object relative to its background.

Having significantly different light levels between work areas can be problematic. Colour contrasts between objects and the background can also affect the workplace. Equipment should be coloured differently to the background to ease visual strain for workers. Painting stationary and moving parts in contrasting colours also improves visibility and reduces injury risk (CCOHS, 2013). Colour blindness affects a number of people and can inhibit them from differentiating between certain colours, so special consideration should be taken when selecting the colour and position of safety information and signs.

Visual field

The visual field is the area that can be viewed by both eyes while the head is stationary (Figure 12.9). This area can be subdivided into three sections; the inner field, the middle field and the outer field. The inner field is the zone of sharpest vision, while items within the middle field aren't very clear – they are detected if strong contrasts or movement is used. Usually, little is noticed in the outer field of vision unless movement occurs (Kroemer, 1997).

Viewing distance

When determining the workplace layout and positioning of light fixtures, it is important to ensure that tasks involving detailed viewing are well lit and located in the centre of the workers field of vision, thus enabling good working postures to be adopted while carrying out work tasks.

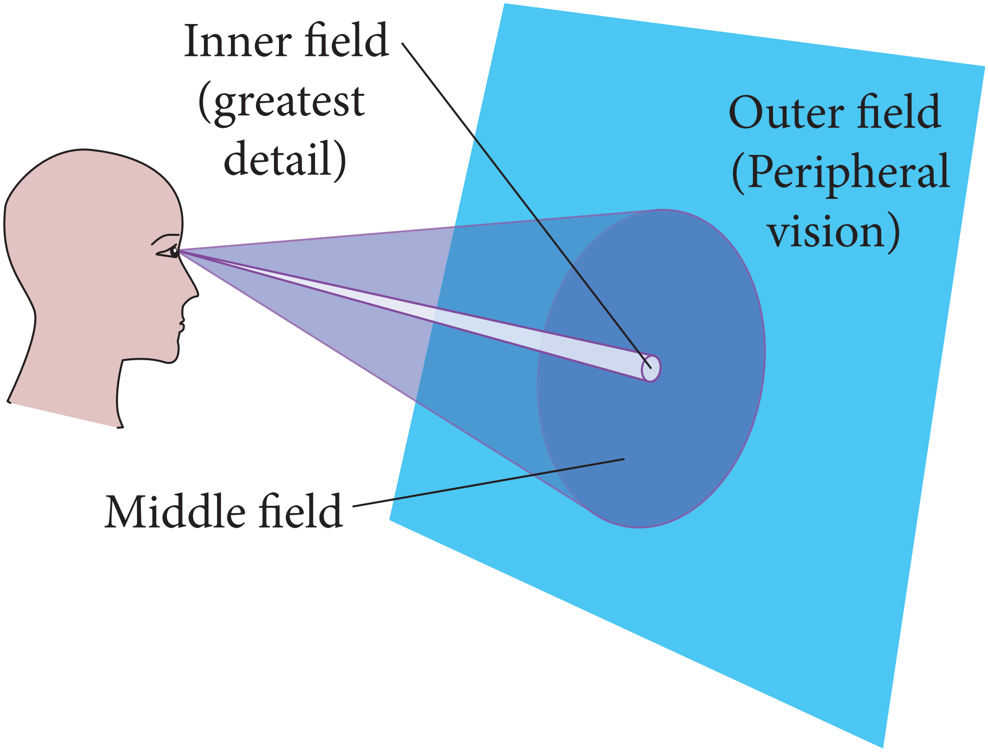

Figure 12.9: Schematics of visual field (adapted from Kroemer, 199 p.297).
Illustration by C. Berlin, based on Kroemer (1997).

12.12. Lighting regulations

A number of standards and regulations have been issued by the Swedish Work Environment Authority concerning lighting conditions in the work environment:

AFS2000:42	Workplace design
AFS1998:5	Working with a computer screen
AFS1993:10	Machine interfaces
AFS1997:11	Cautionary marking
AFS2006:4	Use of work equipment
AFS1998:1	Physical loading, ergonomics
AFS 1980:14	Mental and social work environment aspects
AFS ---	Restaurants, maintenance work, automotive industry, medical controls, explosives, etc.

Glossary

LUMINOUS INTENSITY	Luminous intensity is the quantity of visible light that is emitted in unit time per unit solid angle, Candela (cd).
ILLUMINANCE	Amount of light falling on a surface, measured in Lux (lx).
LUMINANCE	The amount of light reflected or emitted from a surface, measured in candela per m^2 (Cd/m^2).
REFLECTANCE	This concerns the ability of a surface to reflect light, and is expressed as a percentage (%) of reflected light compared to incident light.
GLARE	Excessive or uncontrolled light that impairs vision

12.13. Sound and noise

Sound that can be detected by the human ear is essentially a series of vibrations transmitted through a medium, with frequencies in the approximate range of 20 to 20,000 hertz (Oxford Dictionaries, n.d). Two properties of sound are essential to analysing and designing signals and sound environments; on one hand, *loudness,* measured in deciBels (dB) is the pressure with which the eardrums are physically impacted. The unprotected human ear has physical limitations regarding how much sound pressure it can withstand without sustaining injury, and therefore, loudness is regulated in a healthy work environment. The other property is sound *frequency*, measured in Hertz (Hz), also known as *pitch* or *tone.* Most human ears are differently sensitized to different frequencies; this means that for some pitches, we may require a louder signal to even perceive that a sound is present. For regular human speech, most sounds fall into the frequency range of 250–6000 Hz, where vowels like, a, e and o tend to be low-frequency, and certain consonants (like f, s and th) are high-frequency.

When it comes to aural inputs (what we register through our auditory sensors in the ears), we differentiate sound from noise, where sound is desirable, tolerable signals carrying meaning, whereas noise is unwanted aural input that distracts and causes division of mental resources or discomfort. Noise is subjective and a matter of perception; what one person may consider to be music, another may perceive as noise. There is also the aspect of ambient sound or background sound (such as birdsong, humming machines, murmuring, rolling waves) that our brain is able to filter out or differentiate from meaningful signals. Ambient sound may be borderline to distracting noise, depending on the knowledge and preferences of the individual. In a new environment, initially distracting noise may change over time to ambient sound as we learn to distinguish constantly on-going noises from signals (for example, some people are more skilled than others at filtering out the sound of other people talking in the background, which is often an issue in office landscapes).

Sound signals can be designed to be easily detected (by being different from the ambient sound context), identified and localized. Thanks to binaural (stereo) hearing, we are often able to locate which direction a sound is coming from, since our brain automatically interprets the difference in sound intensity between the two ears (see more in Chapter 5). Sound pressure levels are a logarithmic measure, measured in decibels (dB). Sound signals are commonly used in production environments to alert workers of dangers, e.g. in the form of alarms or sirens.

12.14. Effects of noise

Noise can either be external, coming from outside the building from traffic and other buildings, or internal caused by machines, fans, engines, telephones and people talking. In industrial contexts internal noise can vary considerably depending on the sequence of work tasks. The intermittent clanging of metal, hammering, or hissing spray of paint is commonplace in a production environment. Noise is considered a health hazard as it can trigger hearing loss, cause distraction, mask information, prompt miscommunication and in some cases stress. Prolonged exposure to intense sound can lead to *noise induced hearing loss* (NIHL) over time. For some people, this could occur within a matter of months, while for others the true impact may only be realized years after. Typically loss of hearing is progressive and can also come about through the natural aging process. However, one-off very loud noises can also prompt sudden hearing loss by damaging cells within the ear, known as *acoustic trauma*. A common issue associated with noise is the masking of important information, such as alarms and instructions. Communicating with co-workers can become very difficult in noisy environments, especially when trying to communicate new or complicated technical information. This can be frustrating for workers, and at worst miscommunicated information could prompt severe accidents. Noise can also be very distracting, as you have probably encountered while trying to work in the library and people talking loudly on the other side of the room inhibit you from focusing on your work. Exposure to noise can also have a physiological impact on workers prompting increased stress levels. In addition to the decibel level, the distance of the ear from the sound source and the length of time it is exposed to the sound source are equally important.

12.15. Measuring sound

While it is possible to objectively measure sound, this doesn't always provide information on the disturbing effects of noise in the work environment. So observations and interviews also play an

Table 12.5: Concepts related to sound and noise.

NOISE	• "Unwanted sound" • Health hazard; may contribute to hearing loss • Safety hazard; masks signals, causes irritation and stress
LOUDNESS	• A measure of sound pressure level, measured in Decibels (dB)
FREQUENCY	• The sound property that determines pitch, measured in Hertz (Hz) • The human hearing range is 20 to 20,000 Hz; frequencies below this range are experienced as vibrations • Higher frequencies are the first to be affected by hearing loss • Sounds at extreme pitches (both high and low) cause adverse effects such as pain or nausea
IMPULSE NOISE	• Single short bursts of noise, last less than a second with a peak level 15 dB higher than background noise (Stark, 2003)
AMBIENT NOISE	• The background sound pressure at a given location

important role in determining the levels of uncomfortable noise in the workplace. Sound level meters used to measure sound comprise of a microphone, amplifier, filter and display. A wide variety of meters are commercially available; however, these are of varying quality and accuracy and don't all adhere to international standards, so care should be taken when selecting a tool and where possible only tools with calibration certificates that adhere to international standards should be used.

12.16. Hearing protection

A number of different protective measures exist to reduce the hazardous risks associated with loud noise:

- Hearing Protection Devices (HPDs)
- sound showers (directional speakers)
- sound insulation
- legislation and standards

HPDs are the most commonly used method to protect against high sounds. By wearing earplugs or earmuffs, noise can be damped and the ear protected. However, when worn for prolonged periods of time, these devices can become uncomfortable due to the pressure they exert on contact. *Sound showers* are directional speakers that create a highly focused and directional audio output that can only be heard at a very specific point, so other people in the nearby vicinity cannot hear it. Insulation and sound absorbent materials are often used when soundproofing to convert the energy into another form and prevent it from being reflected around the room. In addition to this equipment, a number of standards and guidelines concerning have been published concerning sound in the work environment, which all companies must adhere to, to minimise potential health risks.

12.17. Vibrations

Vibrations affect our ability to work in both the physical and the mental sense. In a working environment where there is vibration, there is usually also long-term ambient noise which may impair concentration or hearing of important information or signals. In the physical sense, vibrations are a risk because the body tissues and organs absorb the energy from them. Particularly the muscles compensate for the small forces that vibrations expose the body to, both by voluntary and involuntary contractions. If the body is exposed to vibration for a long time duration, this results in excessive low-level static loading, which not only tires the muscles, but also poses a risk to the joints.

As explained in Chapter 4, the joints' contact surfaces are covered with cartilage, to cushion and smoothen the gliding of the bones against each other. Vibrations over long time durations can wear down the layer of cartilage prematurely, causing joint pain and problems. Furthermore, because the cartilage is thinnest at the outer edges, we have the least amount of natural cushioning at the extreme ends of the motion range. This implies that work in extreme postures in a vibrating environment is a particularly hazardous ergonomics risk.

12.18. Whole Body Vibrations

Vibrations appear in many immersive working environments, quite frequently in vehicles such as trucks, buses, ships and forestry equipment, where the body is standing or sitting on a vibrating base. Aside from the risk of injury to muscles and joints, an additional risk factor is that different body tissues have different resonance frequencies, meaning that there is a range of vibrations at which some body tissue will experience local discomfort (Figure 12.10). These resonance frequencies will

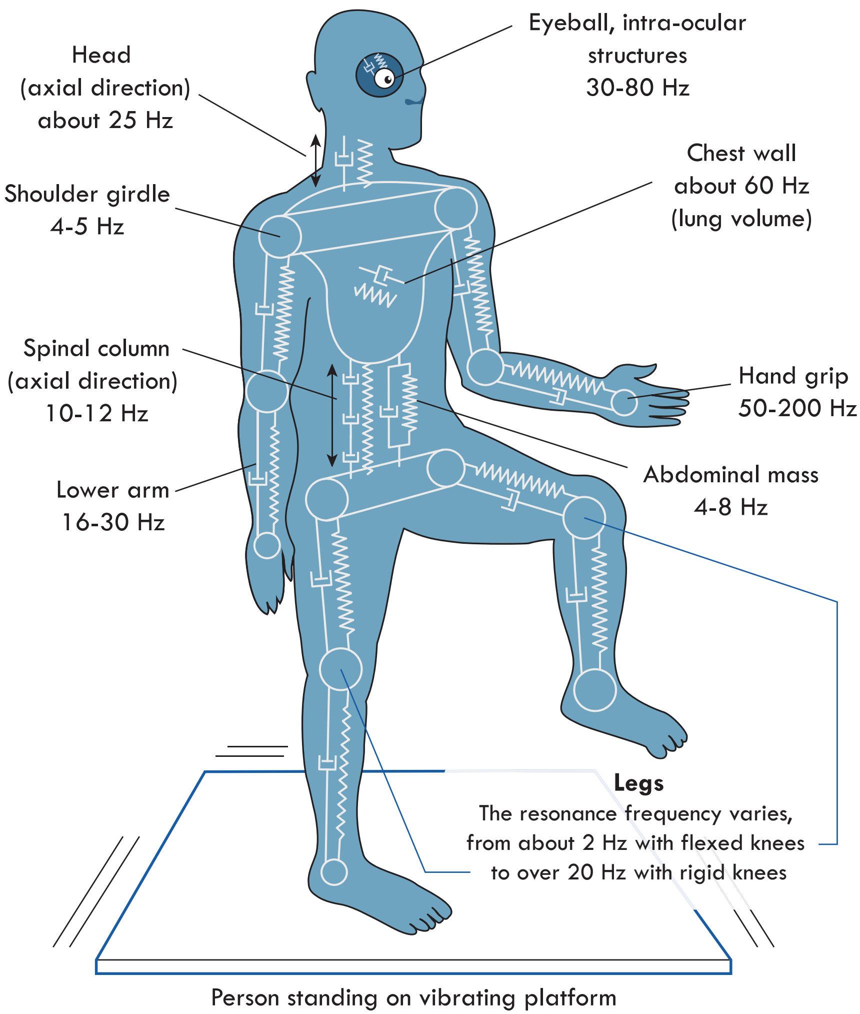

Figure 12.10: Resonance frequencies for different body segments, represented by a simplified mechanical model of a human standing on a vibrating platform.

Image by C. Berlin, based on Rasmussen (1982).

vary from individual to individual but tend to lie within a certain range (for example, the resonance frequency of the shoulder complex typically lies between 4 to 6 Hz, according to Bohgard, 2009 and Rasmussen, 1982).

Not only the joints and muscles are at risk; even the internal organs, eyes, brain and spine are sensitive to vibration at different frequencies. Particularly the eyes at resonance frequency cannot function, leading to impaired visual work due to the vibrating environment.

Low-frequency vertical vibration (lower than 1 Hz) has a particular tendency to cause nausea or drowsiness, depending on the amplitude or intensity and the resonance frequencies of the individual's body segments. This explains why some people can experience motion sickness in a vehicle or ship, while others are lulled to sleep. (Either way, there is a definite impairment to alertness.)

12.19. Hand/arm vibration

In a number of industries, handheld power tools such as chainsaws, pneumatic hammers, grinders and drills are used. As seen in Figure 12.10, frequencies that may be harmful to the arms and hands lie between 16–30 Hz for the lower arm and 50–200 Hz for the hand grip. However, regular use of such tools over a period of time can have severe health consequences and lead to hand-arm vibration syndrome (HAVS), carpal tunnel syndrome (CTS) or arthritis in the wrist or elbow. The symptoms of these syndromes are: vascular, neurological, and musculo-skeletal damage to workers' fingers and hands, tingling and numbness in the fingers, reduced sense of feeling, loss of strength in the hands and episodes of pale, white fingers often triggered by exposure to cold (Work Safe BC, 2013; HSE, 2012). These symptoms can inhibit people carrying out everyday precision tasks such as fastening buttons and pulling zips. Initially these occurrences come and go; however, prolonged continued exposure can make them permanent and irreversible, meaning workers have to change jobs. This damage can be worsened if the workers' hands are cold while they are exposed to vibration.

12.20. Radiation

As mentioned, this book only briefly describes the effects of radiation. Radiation is a mostly invisible environmental factor that has the potential to cause serious long-term ill health effects, and it is important to know something about the range of consequences that may result from radiation exposure. Sources of radiation include equipment, radioactive substances, particles in the air, food, sunlight, lamps, radios and electrically charged materials. Generally, the way to limit radiation exposure is by placing a shield between the source of radiation and the human. The human body absorbs radiation but has the potential to recover from very low doses, as long as sufficient recovery time is allowed between exposures. However, excessive short-term exposure may result in immediate fatal effects. In occupational/industrial hygiene, the remedies to protect workers against radiation are regulation of *time, distance* and *shielding* (OSHA, n.d.).

However, it is important to remember that radiation is also very useful; for example, X-rays allow us to non-invasively identify damages in the body; UV radiation can disinfect surfaces and reveal the presence of materials not otherwise visible to the human eye; microwaves allow rapid heating of food materials; and IR cameras can be used to detect motion in places that are too dark for the human eye to see.

Risk assessments are generally made using equipment that can detect electromagnetic radiation (such as radiation detectors or photomultipliers), and measurement units to determine safe levels of exposure are often in terms of absorbed energy per mass unit of body tissue (e.g. the SI unit sievert, Sv, that measures biological effects of ionizing radiation, or SAR, specific absorption rate) or distance to the source of radiation.

Radiation is commonly divided up into ionizing and non-ionizing radiation, where ionizing radiation has the potential to detach electrons from atoms in human tissue, and non-ionizing does not. A general rule of thumb is that non-ionizing radiation sources can be turned off, while this is not possible for ionizing radiation sources.

Ionizing radiation is considered much more damaging to the human body, as physical damage is more apparent at low doses. Short-wave electromagnetic radiation (such as X-rays), charged particles and radiation from radioactive substances fall under this category, and in most working environments it is strongly recommended to eliminate or limit exposure to such radiation sources. Very large exposures to ionizing radiation during a short time period can result in massive tissue damage or cell death, while even intermediate doses may damage cell nuclei and genetic cells to the point where they may grow uncontrollably, resulting in cancer and possibly hereditary damage. A dose larger than 1 Sv received over a short period of time may cause radiation poisoning, an acute condition that can rapidly lead to death.

Non-ionizing radiation, although considered less acutely damaging, can also result in severe ill-health effects, including cancer. Non-ionizing radiation includes electromagnetic radiation with wavelengths corresponding to visible and invisible light (optical radiation) including ultraviolet (UV) and infrared (IR) light; microwaves; and radio-frequency radiation. Optical radiation has physical effects on both the skin and the eyes; in particular, eye damage can result from excessive exposure to UV rays (for example from the sun).

The effects of these two radiation types are summarized in Table 12.6.

Particularly in the nuclear sector, radiation exposure is tightly regulated by international associations such as the ICRP (International Commission on Radiological Protection) and national ones, such as the Swedish Radiation Safety Authority (SSM), both of whom issue design guidelines, limit values and practices to limit exposure to individuals.

Table 12.6: Examples of effects of ionizing and non-ionizing radiation with increasing severity as exposure increases (adapted from Bohgard, 2009 pp. 293–303).

	Ionizing	**Non-ionizing**
Low to intermediate doses	• Cell damage due to detachment of ions in tissues	• Absorption of energy in human tissues • Altered magnetic fields in the body • Thermal effects (increase in temperature) • Photochemical effects (excited atoms in tissues, resulting in chemical changes)
Higher doses	• Cancer	• Skin pigmentation (UVA rays) • Irritation and potential damage of eyes, snow blindness (UVB rays)
	• Radiation poisoning	• Eye damage (IR radiation) • Cancer (e.g. skin cancer from UV exposure)

Study questions

Warm-up:

Q12.1) Name at least three (each) of the physiological effects of extreme heat and cold.

Q12.2) What are the risks of being exposed to full-body vibration? Name two examples.

Q12.3) Name at least three solutions that counteract noise.

Q12.4) What is glare?

Q12.5) Name three important characteristics of a sound used as an alarm signal.

Q12.6) What is the difference between ionizing and non-ionizing radiation?

Q12.7) Name three disadvantages of protecting humans from extreme temperatures using clothing and protective gear.

Look around you:

Q12.8) Research online for different types of measurement equipment for different work environmental factors (thermal climate, lighting, sound, vibrations and radiation) and try to get a feel for the price ranges that exist – which types of equipment are very costly, and why?

Q12.9) When you encounter a new workplace, try to take note of the conditions of thermal climate, lighting, sound environment, vibration sources and evidence of dust or chemicals. How many of the conditions you observe have an explanation that is connected with the workplace operations? Is the best course of protection to remove the source of exposure, to shield it, or to protect the workers using protective gear?

Connect this knowledge to an improvement project

- If work environment assessments are going to be a frequently occurring activity, it may be a good idea to invest in a toolbox of measurement devices that cover a range of environmental factors. Equipment that measure sound/loudness, temperature and humidity, lighting, vibrations and radiation come in many degrees of sophistication and price ranges, and some are associated with standards that regulate appropriate exposure levels.
- If the workplace you are assessing has an occupational hygienist or work environment representative, they may be a very good informant who can supply good knowledge about that particular work site's conditions, risks and regulations that it abides under. If possible, communicate with that person and discuss solutions that will potentially impact their area of responsibility. This person may also be well informed about chemical and other exposure hazards common to that workplace.

Connection to other topics in this book:

- Many work environmental factors influence the human capability for cognition (Chapter 5) and ability to perform physical work (Chapter 2), both by overloading human senses and locomotive structures and by requiring awkward protection gear and equipment.
- Unfit lighting conditions may cause a worker to adapt their posture to be able to see the work they are performing, which may lead to physical overloading (Chapter 3).
- Psychosocial conditions (Chapter 6) may be affected if workers are in a thermal climate or sensory-overloading environment (with regard to sound and noise) that makes work more strenuous.
- Exposure to vibration may cause long-term serious injuries to different body structures or cause nausea (Chapter 2).

Summary

- Several different factors can cause mental, psychological and physical loading on the body; five main areas are thermal climate, air quality, lighting, sound, vibration and radiation.
- The discipline of occupational hygiene addresses these and many other work environmental factors but includes a wider scope of topics (e.g. chemical exposure, air quality etc.) due to the fact that many occupational hygienists start out as physics or chemical engineers.
- The ideal thermal climate, also known as the comfort climate, is the psychophysical state in which humans experience satisfaction with the climate and so is best for working.
- Suitable clothing for the task and temperature conditions should be worn.
- Suitable lighting that illuminates the working area without causing glare or reflections should be used.
- Sound can be differentiated from noise. Where sound is considered desirable carrying meaning, noise is unwanted, distracting aural input.
- Ambient sound may act as distracting noise, depending on knowledge of the environment and the individual's cognition processes.
- In some workplaces, hearing protection is required to protect workers' ears from noise induced hearing loss (NIHL).
- Vibrations can affect the human's ability to work, both in the physical and mental sense.
- Vibrations are present in a number of work environments, causing injury to muscles, joints and body tissue.
- Low-frequency vibrations can cause nausea and drowsiness.
- In industries using power tools, hand-arm vibrations (HAV) are frequently occurring and can trigger injury, resulting in tingling, discomfort and reduced capacity for tactile feeling in the hand.
- Radiation is predominantly an invisible environmental factor that has potential to cause serious long-term ill health effects; exposure over prolonged periods of time should be monitored.

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