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A literature review of the effects of environment microclimatic conditions on the slip potential for flooring

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RESEARCH REPORT 471

A literature review of the effects of environment microclimatic conditions on the slip potential for flooring

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The Health and Safety Executive (HSE) has published a wide range of publications concerning the risk of slips and trips along with practical measures that can be taken to minimise the risk. These publications have recently been supplemented by the CIRIA publication C652: Safer surfaces to walk on - reducing the risk of slipping. This publication provides comprehensive guidance concerning building elements, flooring types and characteristics, contamination, cleaning, footwear and human factors. Environmental factors, and in particular, the slip potential resulting from condensation, are touched on with no detailed guidance provided. This is also the case for the current HSE publications.

In response to this the HSE require research to be performed concerning the effects of microclimate conditions on the risk of slipping and tripping, an investigation of which building services solutions are the most effective at reducing the risk, along with the preparation of guidance and training/educational material for those managing existing buildings and constructing new buildings. As a first phase to this work the HSE require details of what information is available concerning the impact of microclimatic conditions on the slip potential for flooring.

The work detailed in this report comprised a literature/information review considering the following environmental parameters: internal air temperature, surface temperature, relative humidity, ventilation and air movement. Other environmental factors that can impact on the risk of slips and trips such as lighting and noise are also considered although in less detail.

The review provides information on how building services impact on the above environmental parameters and what considerations/strategies are applicable in order to minimise slip potential.

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1 INTRODUCTION

The Health and Safety Executive (HSE) has published a wide range of publications concerning the risk of slips and trips along with practical measures that can be taken to minimise the risk. These publications have recently been supplemented by the CIRIA publication *C652: Safer surfaces to walk on – reducing the risk of slipping*. This publication provides comprehensive guidance concerning building elements, flooring types and characteristics, contamination, cleaning, footwear and human factors. Environmental factors, and in particular, the slip potential resulting from condensation, are touched on with no detailed guidance provided. This is also the case for the current HSE publications.

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The review provides information on how building services impact on the above environmental parameters and what considerations/strategies are applicable in order to minimise slip potential.

2 INFORMATION SEARCH METHODOLOGY

Relevant information was identified by means of the following.

1) Database searches

The OSH UPDATE database was searched. The database comprises the following specific databases which specialise in health and safety issues:

- European Agency for Safety and Health at Work database
- CISDOC – International Labour Office CIS Health and Safety Centre database
- European Union legislation
- UK Legislation database
- HSELINE – UK Health and Safety Executive
- UK Royal Society for the Prevention of Accidents
- NIOTICS – US National Institute for Occupational Safety and Health
- RILOSH – Canada Ryerson University
- OSH standards specifications

BSRIA's IBSEDEX database was also searched. This database includes abstracts relating to building services.

2) Internet searches

Internet searches were made using the Google search engine.

3) Special interest groups and individuals

The Contact Group for Slips, Trips and Falls (CGSTF) was contacted and an email request for information sent to the group's research forum.

4) BSRIA ENews

An article outlining the project along with a request for feedback/information was included in the February edition of BSRIA's ENews. This electronic news letter is send to approximately 20,000 contacts comprising BSRIA members and contacts, subscribers to the Barbour information service and members of the British Institute of Facilities Managers (BIFM).

3 SEARCH RESULTS

Very few sources of information were identified specifically linking environment microclimatic conditions with the slip potential of flooring. Of those identified the majority are published by the HSE. A far wider range of publications were identified concerning how building services impact on the environment microclimatic conditions which in turn can affect the risk of slipping. The following outlines sources of information concerning the impact of microclimatic conditions (including lighting and noise) on the risk of slipping while the impact of building services on microclimatic conditions is discussed in Sections 5 and 6.

The HSE publication *HSG 155: Slips and trips – Guidance for employers on identifying hazards and controlling risks*[1] makes reference to smoke/steam obscuring a person's view and suggests eliminating or controlling it by redirecting it away from risk areas and improving ventilation. The following guidance is provided concerning lighting:

- Lighting should enable people to see obstructions on floors, potentially slippery areas etc so they can work safely. Replace, repair or clean lights before lighting levels become insufficient for safe working.
- Arrange lighting and light fittings so they do not create dazzling light or glare that can make it difficulty to see. Ensure light levels are not reduced, for example by goods stacked in such a way as to block light or cast shadows.
- Local lighting should always be provided at staircases and changes of level; it is usually also needed at ramps where there is no change in colour, texture or flooring material from level walkway to ramp.

The HSE publication *INDG 225 (rev 1) – Preventing slips and trips at work*[2] replicates/summarises the guidance provided in *HSG 155*.

The HSE publication HSG 156: Slips and trips – Guidance for the food processing industry[3] highlights the need to make sure that the prevailing conditions allow visibility of, and concentration on, floor conditions. The guide states that the environment should not interfere with people's ability to notice slippery contamination on the floor, for example low light levels, shadows and glare. The guide also indicates that excessive noise and extreme temperatures can be factors that adversely affect concentration. Reference is made to the prevention of contamination becoming deposited on walking surfaces with the extraction of grease-laden air, such as cooking fumes and condensation and moisture, preferably at source by specialised local extraction equipment.

The HSE publications *CAIS6 (rev 1): Catering Information Sheet No 6 – Preventing slips and trips in kitchens and food service*[4] and *EDIS2: Food Sheet No 6 – Slips and trips – Summary guidance for the food industry*[5] also emphasise the need to have good extraction and ventilation to remove steam and grease before it can be deposited. In addition, *CAIS6* also states that drainage channels should be used to carry water, steam drips and waste away from tilting kettles, bratt pans and other equipment. (In addition to resulting in a direct source of floor contamination, areas of water on a floor will tend to increase levels of relative humidity which could result in condensation on cold surfaces in adjacent areas with low air/surface temperatures.)

The HSE publications *EDIS2: Education Information Sheet No2 – Preventing slip and trip incidents in the education sector*[6] and *HSIS2: Health Services Sheet No2 – Slips and trips in the health services*[7] reiterate the need for adequate ventilation in order to prevent condensation along with the requirement for adequate lighting. In addition, HSIS2 suggests the use of underfloor heating, particularly in entrances to limit the effects of contamination (the higher floor temperature will quicken the drying time following water contamination from outside sources and wet cleaning). The publication also highlights the need to promptly repair leaks.

The need for proper floor cleaning is discussed in the HSE publication *Slips and Trips 2 – The importance of floor cleaning*[8] as is the need for proper drying. The publication states that very small amounts of contamination can present a real slip problem and points out that even a well-rung mop will leave a thin film of water which is enough to create a slip risk on a smooth surface. Note that building services strategies such as underfloor heating and microclimatic issues including ventilation, air movement and air temperature will impact on the drying time of floors.

The Trades Union Congress (TUC) along with UNISON, NASUWT, and NGSU provide guidance on their websites[11-14] concerning slips and trips. The guidance appears to be sourced from the various HSE publications. Reference is made on the UNISON website and *Health and Safety Information Sheet – Slips and trips*[15] to the need to provide adequate lighting; adequate ventilation to avoid the build-up of condensation; and maintaining equipment and the work environment to prevent leaks.

The CIRIA publication *Safer surfaces to walk on – reducing the risk of slipping*[16] briefly addresses environmental issues that can affect the risk of slipping. These are lighting, condensation and noise. Concerning lighting the publication outlines the following design issues:

- Level of lighting – required lighting level for background and task specific applications
- Variation in lighting – avoidance of high levels of contrast
- Glare – avoidance of glare especially on shiny floor surfaces
- Control of lighting – requirement for manual switching on/off of lighting
- Night lights – provision for lighting at night to assist the elderly.

Condensation is noted as a form of contamination that presents a slip risk with it forming on floor surfaces or on other surfaces such as walls, glazing, ceilings etc then running or dripping onto floor surfaces.

Concerning noise as a risk factor the CIRIA guide notes that there is a "dearth" of research data concerning this factors influence on slipping although it suggest that a slip risk may occur if a sudden loud noise startles a person or if the ambient noise level is loud enough to affect a person's ability to hear instructions or a warning.

The European Agency for Safety and Health at Work in their short publication *FACTS 14 – Preventing work-related slips trips and falls*[17] provide summary guidance on the topic including the need for adequate lighting. No information is provided concerning microclimatic conditions.

In the *Guide to preventing slips, trips and falls* [18] the Australian Government emphasis the following:

- Need for adequate lighting
- Use of "engineering methods" to control hazards at the sources (the example given in the publication relates to the provision of suitable drainage arrangements)
- Inspection and maintenance of plant and equipment
- Installation of exhaust systems to remove dusts or vapours that would otherwise settle on floors.

The American Welding Society in their fact sheet *Tripping and Falling*[19] makes brief reference to sudden loud noises as being a possible cause of tripping and falling.

BS 5250:2002 – Code of practice for control of condensation in buildings[20] notes that condensate on certain floor types can lead to a slip hazard.

4 MICROCLIMATE INFLUENCE ON SLIPS & TRIPS

The risk of slipping on a flooring surface is greatly increased if the surface is wet. Floor surfaces typically become wet because of either contamination (eg spilt fluids or water brought in from the exterior on the soles of shoes) or condensation.

Condensation will form on a surface if its temperature is less than the dew point temperature of the air in contact with it. A floor surface may become wet due to direct condensation or by means of dripping from a ceiling or runoff from walls and glazing.

The factors that influence the formation of condensation comprise:

Internal relative humidity. Defined as the ratio of vapour pressure to saturation vapour pressure at the same dry bulb temperature, expressed as a percentage, relative humidity provides an indication of the air's ability to "hold" moisture. When the air is cooled to its dew point condensation will form. The air temperature and the amount of water vapour present in the air directly influence relative humidity such that cold and damp internal air will have high relative humidity compared to hot and dry air. In practice the amount of space heating provided and the internal generation of moisture will affect the relative humidity. The latter is a function of the number of building occupants and the activities and processes that take place within the building. Some activities and processes such as those relating to canteens, kitchens, laundries and shower rooms etc can generate large amounts of moisture.

Internal surface temperatures. As was mentioned, condensation will form on a surface if its temperature falls below the dew point temperature of the air in contact with it. Therefore in order to avoid condensation the internal surface temperatures of a building must be maintained above the dew point temperature. This can be achieved by maintaining a high enough internal air temperature and/or limiting the heat loss through the building fabric. *BS 5250:2002 – Code of practice for control of condensation in buildings*(20) provides guidance on construction techniques to avoid the risk of condensation. In addition *Approved Document L - Conservation of fuel and power*(21) relating to the Building Regulations provides minimum U values for building elements in order to avoid condensation. (Note that a U value is a measure of a building element's heat transfer characteristics.)

BS EN ISO 13788:2002 – Hygrothermal performance of building components and building elements. Internal surface temperature to avoid critical surface humidity and interstitial condensation. Calculation methods(22) gives calculation methods, primarily intended for assessing the risk of mould growth and interstitial condensation. However, they can also be used for assessing the risk of surface condensation.

Ventilation. The internal generation of moisture and its effect on internal relative humidity can be mitigated through the use of ventilation, either mechanical or natural, or a combination of both. In addition to ventilation, air infiltration can also reduce levels of relative humidity. (Air infiltration is the uncontrollable exchange of air from the exterior resulting from gaps in the building fabric and the permeability of the materials comprising the building fabric.)

In certain circumstances ventilation and infiltration can increase the risk of condensation when the outside relative humidity is greater than the inside level and most notably during a period of "warm front condensation"(23). Here condensation can occur when the weather changes at the end of a cold spell and the cold air is replaced within a short period of time by warm moist air. For heavyweight structures (high thermal mass) the relative humidity of the air in contact with the building fabric will rise faster than the fabric surface temperature and condensation will occur. This is most likely to occur where the building fabric is unheated and the infiltration rate is high, eg warehouses and storage buildings.

Minimum requirements for ventilation in buildings is provided in *Approved Document F – Means of ventilation*[24] relating to the Building Regulations. *Approved Document F* is primarily concerned with ventilation in order to remove internally generated pollutants and to limit the accumulation of moisture, which can lead to mould growth and present a risk to health.

Linked to ventilation is the concept of "ventilation effectiveness" which for mixed ventilation systems requires the incoming fresh air to mix with the room air. Simply supplying and exhausting the correct quantity of air will not be adequate unless the supply air is distributed properly and the exhaust air carries away the internal contaminants (including moisture in the air). Poor ventilation effectiveness can lead to areas with relatively stagnant air which will be slow to evaporate condensation.

The above factors that influence the formation and removal of condensation are in turn influenced by the provision of building services. The following sections review building services considerations and strategies to help alleviate the risk of slipping along with discussing the circumstances where building services can act as a risk factor and increase the possibility of slipping. Lighting and noise issues are also discussed.

5 REVIEW OF BUILDING SERVICES CONSIDERATIONS/STRATEGIES TO HELP ALLEVIATE RISK

5.1 HEATING SYSTEMS

As was discussed in Section 4 the risk of condensation forming on floor surfaces is in part a function of the internal air temperature and the surface temperature of the surface in question. Issues relating to the avoidance of condensation/slip risk relate to the warm-up times of the space to be heated and the associated surfaces along with the uniformity of the heating effect. Space heating in buildings can be provided by means of dedicated heating systems and/or air conditioning systems. The latter is discussed in Section 5.3, while the former is discussed below.

The main types of heating systems prevalent in the UK are[26]:

- Radiator systems. These are generally used in naturally ventilated buildings, but can also be used in some types of mechanically ventilated and air-conditioned buildings. They are typically located around the perimeter walls to offset cold down draughts from the glazing and prevent condensation. A disadvantage of this type of system is the inherent slow thermal response resulting in a time delay before the air and more particularly the building fabric reaches the desired temperature. Also, heat output is mostly convective which can lead to an uneven temperature gradient in the space.
- Convectors. These heaters can be either natural convectors or fan convectors. Natural convectors usually consist of a casing with top and bottom openings, and a finned hot water pipe at low level. The hot water pipe creates an upward convection current of hot air within the casing, pulling room air in at the bottom and pushing hot air out at the top. The main benefit of convectors in comparison to radiators is their greater heat output per unit size and their quicker warm up time. Fan convectors (also known as forced convectors) incorporate one or more fans which increase the heat output per unit size and improve air movement in the space.
- Underfloor heating. There are two types of underfloor heating: low temperature hot water systems and embedded electric element systems. Both types comprise a matrix of either plastic pipework or heating cable embedded between a top layer of screed and the floor slab below. Underfloor heating is suited to certain types of public spaces, foyers and shopping complexes etc and can overcome the problems of a cold surface normally associated with stone floors and other such coverings (formation of condensation when considering the risk of slipping). This type of system can provide relatively even temperature distribution across the floor and throughout the space, with minimal or no stratification at high level. A disadvantage is the slow heat-up times and slow response to changes in temperature setting. In practice this may not be an issue as the underfloor heating systems are often kept on continuously during the heating season to provide background heat. Also, the heat output is largely self-regulating – as the air temperature in the room increases towards that of the floor, heat output diminishes naturally.
- Warm air unit heaters. These are typically used in industrial applications and burn natural gas, propane or oil and are either free standing or mounted at high level. From the perspective of avoiding condensation on floor surfaces (or evaporating condensation/contamination) the major drawback of this type of heating is that the heat output is convective which can result in warm air building up at high level (stratification). This may require the use of fans to create air movement and circulate heat evenly throughout the space. This problem is more acute with high-level units.
- Radiant heating. This type of heating is typically used in buildings such as warehouses, industrial units and sports halls. Radiant heating can be directly gas-fired, electric or fed by a hot water system. High temperature radiant heating can pre-

heat a building far more rapidly than is possible with a warm air system and air movement is not required to distribute heat throughout the space. However, depending on the layout of the heating units and the layout/contents of the building some areas of the building can be left relatively unheated. Any such areas may be prone to the formation of condensation or a slower evaporation of formed condensation or contamination.

The HSE publication *HSIS2: Health Services Sheet No2 – Slips and Trips in the Health Services*(7) suggests the use of underfloor heating to limit the effects of contamination, particularly in building entrance areas. By providing an even and constant source of heat directly to the floor surface liquid contamination will be evaporated relatively quickly. In addition the heated surface will prevent the formation of condensation. Underfloor heating therefore provides the best solution in many situations to the problem of microclimate induced slip risk.

BS EN 1264: Floor heating – Systems and components(28) provides comprehensive guidance for the design of underfloor heating systems. This guidance includes the following key considerations:

- Thermal boundary conditions
- Calculation of the heat flow density
- Determination of the design supply temperature and flow rate
- Thermal insulation requirements
- Structural preconditions
- System equipment
- Installation of pipes and coupling.

Further guidance is provided in the following publications:

- *Screeds with underfloor heating – Guidance for a defect-free interface. IEP 11/03. BSRIA*(29)
- *Underfloor heating systems – The designer's guide. AG 12/01. BSRIA*(30)
- *Underfloor heating systems – An assessment standard for installations. AG 13/01. BSRIA*(31)
- *Underfloor heating – Design and installation guide. CIBSE*(32)

5.2 VENTILATION SYSTEMS

5.2.1 Mechanical ventilation

Mechanical ventilation comprises the following types(26):

- Extract only. This type of approach is generally used in environments where air becomes directly contaminated by a particular activity or process, examples include: kitchens, factories and industrial buildings. The benefits of this approach with respect to microclimate impact on slip risk are that the localised extraction prevents contamination of adjacent areas and the extraction of contaminated air is assured. Disadvantages relate to the limited control of air movement in the building other than the area in close proximity to the extract point.
- Supply only. This type of system has limited applications but is more suited to ventilating occupied spaces than extract only as the pattern of air movement is more controllable. Typical applications include mixed-mode ventilation, roof-mounted warm air units and services plant room ventilation.

- Supply and extract. A supply and extract system comprises a central air handling unit (AHU) typically containing separate supply and extract fans, air filter and heating coil. A ductwork system is used to supply and extract air in the building. A mechanical supply and extract system can provide the overall heating and ventilation solution for a building or it can be part of a more complex air-conditioning system incorporating cooling and humidity control. Benefits of a supply and extract system are the provision of a constant, reliable rate of ventilation along with a controlled pattern of air movement in a space ensuring even distribution.

Design considerations and guidance concerning mechanical ventilation are provided in *CIBSE Guide B2 – Ventilation and air conditioning*(33).

A key design issue relating to the use of mechanical ventilation systems is room air diffusion. The effectiveness of the ventilation system (and air conditioning system if it includes ventilation) will depend on the method by which air is supplied to and extracted from the space. The parameters that influence this are:

- Air supply velocity
- Temperature differential between the room and supply air
- Position of the supply terminals
- Room shape and geometry, including projections
- Position, size and shape of all sources and sinks for heat
- Temperature of any heat sources and sinks
- Other factors influencing air movement, such as movement of the occupants and machinery, and air infiltration.

If supply air terminal devices (devices that introduce the air into the zone, eg diffusers and perpendicular jets) are poorly selected or positioned this can result in stagnation of the air, draughts, inappropriate mixing and large temperature gradients. The terminal type and layout may be affected by architectural or structural considerations.

Airflow patterns for different types of terminals are strongly dependent on the Coanda effect. This effect is due to the frictional losses between the air jet and the surface and result in the air "sticking" to the surface as it moves over it. This effectively increases the throw of the terminal. If the Coanda effect is not present the maximum throw for a terminal will be reduced by approximately a third. The main factors that influence whether or not the Coanda effect will occur are the:

- Distance between terminal and surface
- Width of jet exposed to the surface
- Velocity of the jet
- Presence of projections and other disturbances.

The positioning of exhaust terminals are less critical than supply terminals as the opening has little influence on the airflow pattern in the space because the zone of localised high velocities associated with exhaust openings is very close to the opening. Despite this, exhaust terminals can help minimise condensation and/or aid the removal of contamination by placing them in a stagnant zone where the supply jet influence is limited and close to any cold surfaces to help increase the surface temperature.

5.2.2 Natural ventilation

Natural ventilation comprises the following types:

- Single-sided ventilation. Single-sided ventilation is a space primarily ventilated by wind entering one or more openings within a single external wall. This is the simplest form of natural ventilation but is dependent on the presence of wind for good ventilation. It is not suitable for deep-plan spaces.
- Cross ventilation. Cross ventilation is an effective way to achieve a high rate of ventilation and can be used in relatively deep-plan offices. Wind drives air through open windows on the windward side of the building and open windows on the opposite side allow stale air to escape. Benefits of this approach include possible high rates of ventilation under favourable wind conditions, however effective cross ventilation requires a relatively clear path for air to flow across the space. Like single-sided ventilation it is dependent on the presence of wind for good ventilation.
- Stack ventilation. Stack ventilation is the process of buoyant, warm air rising upwards in a building and exiting through one or more high-level openings. The air displaced from the building causes cooler fresh air to be drawn into the building through low-level openings, such as doors, windows and vents. The main benefit of stack ventilation is that the temperature difference between the inside and outside of a building is the driving force. Therefore ventilation can be provided on hot still days when there is little or no wind. To work properly a relatively clear path is required for air to travel easily from low level to the high-level ventilation opening. In practice, stack ventilation systems are often combined with wind-driven ventilation for improved performance.

Modern natural ventilation strategies can be relatively complex including the use of automatic control of vents and dampers based on monitoring and/or prediction of weather conditions.

Guidance concerning the design of natural ventilation systems is provided in the following publications:

- *Natural ventilation in non-domestic buildings. AM 10. CIBSE*(34)
- *Air distribution in naturally ventilated offices. TN 4/99. BSRIA*(35)
- *Control of natural ventilation. TN 11/95. BSRIA*(36)
- *Making natural ventilation work. GN 7/00. BSRIA*(37)

Key design considerations with respect to minimising the risk of slip through the provision of suitable microclimatic conditions are:

- Selecting the most appropriate ventilation strategy
- Establishing the required air flowrates
- Establishing the required air flow patterns
- Avoiding the risk of draughts in order to minimise the risk of occupants shutting or blocking vents and hence reducing ventilation rates
- Selecting the optimum control strategy to deliver the required flowrates and patterns.

5.2.3 Mixed mode ventilation

Mixed mode ventilation is a term that describes a system which combines natural and mechanical ventilation. The mechanical element can be extract, supply or a combination of the two, however it is typically a supply system. The mechanical element ensures that an adequate air flow is maintained when natural ventilation is insufficient. Mixed-mode systems have become more popular in recent years. This is largely because greater reliance can be placed on them to provide ventilation in comparison to a passive system (natural ventilation), while still providing the benefit of a passive system when weather conditions are suitable.

A key design consideration relates to the means of control of the mixed mode system in order to ensure adequate ventilation rates and distribution patterns for both operational modes. The changeover between passive and mechanical ventilation can often be crucial.

Guidance concerning the design of this type of system is provided in the CIBSE publication *Mixed Mode Ventilation – AM13*(38).

For all types of ventilation system analysis of air movement may be needed in order to confirm the likely performance of a design. Techniques available include computational fluid dynamics (CFD), physical models and air flow models. Depending on the technique and the ventilation system being modelled, parameters such as air velocity, movement and temperature, volume flow rate; sizing and positioning of vents/openings and terminal devices can be determined. In the case of mechanical ventilation non-standard situations are sometimes assessed using a mock-up to confirm the flow characteristics of specific air terminals.

5.3 AIR CONDITIONING AND DEHUMIDIFICATION

An air conditioning system may have three main impacts on the slip potential of flooring. Depending on the type and specific design of the system these relate to the following:

- Heating. If available, the heating mode of an air-conditioning system will raise internal air temperatures and surface temperatures and help avoid the formation of condensation and/or help evaporate condensation.
- Control of humidity. If an air-conditioning system includes equipment for controlling relative humidity this will help avoid condensation and increase contaminant evaporation by lowering the relative humidity of the air.
- Ventilation and air movement. The ventilation and air movement provided by an air conditioning system will assist in the lowering of relative humidity and the evaporation and removal of contaminants.

The different types of air conditioning and their characteristics with regard to slip potential are outlined below(26):

- Constant volume. Constant volume air conditioning systems are simple systems often used to provide tempered fresh air in multi-zone buildings containing partially centralised air/water systems, eg fan coil installations. As the name suggests constant volume systems provide a fixed volume of air at a temperature and humidity determined by the conditions of the space being served.
- Variable air volume. VAV air conditioning is an all air system which can meet the requirements for the individual cooling/heating of multiple zones, typically within offices. Air is supplied at a constant temperature from the central plant to VAV terminal units which regulate the amount of air entering the zone. Fan assisted terminal units can be used to provide better airflow patterns (primarily the avoidance of “dumping”).
- Displacement ventilation. In this type of system cool air is supplied at a low velocity from a low level wall-mounted or floor-mounted ventilation terminal located within the occupied zone. The cool air initially remains at floor level where it moves across the space. Natural convection from internal heat sources, such as equipment and

occupants, cause upward movement in the space. The warm air collects below the ceiling, where it is extracted by a mechanical extract system.

- Fan coils. A typical fan-coil unit comprises a fan, heating coil, cooling coil and air filter, all housed in a metal casing. The fan draws a combination of room air and fresh air through the filter and across the heating and cooling coils before supplying the air to the zone using supply diffusers. (Note that there is a risk of water leakage from overhead fan coils into the space below.)
- Chilled beams. This type of system comprises a long rectangular unit containing a finned tube through which chilled water is pumped. The beams are typically arranged above, or partly below, a false ceiling. Warm air rising up in the space passes over the beams, where it is cooled and falls back into the space. Chilled beams are also available which incorporate small fans to assist air movement. Chilled beams require a separate ventilation system to supply fresh air to the space.
- Chilled ceilings. Each unit of a chilled ceiling typically comprises a small bore chilled water pipe arranged in a serpentine pattern and attached to the upper surface of a thin metallic ceiling pattern. The panel is cooled through contact with the chilled-water pipework and in turn cools the space. Chilled ceilings require a separate ventilation system to supply fresh air to the space. (Note that there is a risk of water leakage from chilled beams and ceilings into the space below along with the risk of condensation unless the system is controlled properly – See Section 6.4.)
- Split systems. Split systems comprise two main components: one or more indoor room cooling units, and an outdoor refrigeration unit which dumps heat taken from the building. The indoor and outdoor units are linked by pipes which transport refrigerants between the units. Some split systems can operate as a heat pump to provide cooling and heating. Simple split systems only re-circulate room air and cannot provide ventilation (more sophisticated designs can allow the supply of ventilation air).
- Variable refrigerant flow systems. This is a development of split systems the difference being the ability to provide heating or cooling from each of the indoor units on an individual basis. Some concealed indoor fan coil type units can be configured to provide fresh air in addition to recirculating room air.

The table below summarises the air distribution and humidity control characteristics of the different types of air conditioning systems outlined above.

Table 1 Air Distribution and Humidity Control

System type	Air distribution	Humidity control
Constant volume	Very good	Direct
Variable air volume	Very good	Direct
Fan coil units	Fair to good	Indirect
Chilled beams	See note	Indirect
Chilled ceilings	See note	Indirect
Displacement ventilation	Good	Indirect
Split systems	Poor	Indirect
Variable refrigerant flow	Fair	Indirect

Note: Quality of air distribution is difficult to categorise, as it will be influenced by the type of ventilation system installed. The effectiveness of chilled beams will also vary depending on whether they are active or passive, ie if they incorporate a fan to assist the airflow (active), or whether they are reliant on natural convection (passive).

The control of relative humidity, and hence the avoidance/minimisation of condensation along with the evaporation of contaminants can also be achieved with the use of dedicated dehumidifiers. These devices can be located in a room with high relative humidity and used to remove moisture from the air. Typically they cool the air below its dew point where the water in the air condenses and is collected. The air is then reheated before re-entering the room space. Other dehumidification techniques such as the use of desiccant materials can also be used.

5.4 LIGHTING

The *Workplace Health, Safety and Welfare Regulations 1992* require every workplace to have suitable and sufficient lighting. The Regulations state that lighting in the workplace, should as far is possible be natural. The Regulations comment on excessive light and glare, the need to light stairs, and the arrangement of artificial lighting so as to avoid discomfort. Suitable and sufficient emergency lighting is also a requirement. The HSE publication *Lighting at work*(39) provides relevant guidance.

Approved Document M – Access to and use of buildings(40) and *BS 8300 – Design of buildings and their approaches to meet the needs of disabled people*(41) includes requirements for lighting and their control. *BS 8300* states "Good artificial lighting is crucial in ensuring that visually impaired people are able to use buildings conveniently and safely. The illuminance on interior surfaces, the quality of the lighting, good colour rendering and the avoidance of glare are key factors to be considered".

A wide range of parameters need to be considered when designing a lighting system. The *CIBSE Code for lighting*(42) provides guidance concerning the following key design considerations:

- Illuminance
- Illuminance variation
- Luminance and illuminance ratios
- Glare
- Colour appearance and rendering.

The *CIBSE Code* for lighting provides guidance on the design of lighting systems with requirements for specific types of buildings. For each building type the following design data is provided:

- Maintained illuminance
- Limiting glare rating
- Minimum colour rendering.

More in-depth guidance for a range of building types is provided by CIBSE including the following lighting guides:

- *LG5* *Lecture, teaching and conference rooms*(43)
- *LG7* *Office lighting*(44)
- *LG8* *Museums and art galleries*(45)
- *LG9* *Lighting for communal residential buildings*(46)

A range of design checks concerning lighting systems are provided in the BSRIA publication *Design checks for electrical services*(47).

Emergency lighting systems are a requirement in non-domestic buildings in order to aid the safe evacuation of occupants during emergency situations where the main lighting system has not activated or has failed. During an emergency the risk of slipping and tripping is high. The design of these systems is influenced by a range of published requirements and guidance including:

- *Approved Document B1 – Means of warning and escape*(48)
- *BS 5266:1999. Emergency lighting – Part 1: Code of practice for the emergency lighting of premises other than cinemas and certain other specified premises used for entertainment*(49)
- *BS EN 1838:1999/ BS 5266-7:1999. Lighting applications – Emergency lighting*(50)
- *BS EN 1838:1999/ BS 5266-7:2004. Emergency escape lighting systems*(51)
- *BS EN 60598-2-22:1999. Luminaires: Particular requirements – Luminaires for emergency lighting*(52)
- *Emergency lighting design guide. CIBSE Lighting guide 12*(53)

The BSRIA publication *Design checks for electrical services* provides design checks for the following key considerations:

- Required illuminance levels and ratio of minimum and maximum
- Limitation of glare
- Location of luminaires
- Requirements for power supply.

5.5 NOISE

Noise levels in the working environment are currently governed by the *Noise at Work Regulations 1989*(54). These Regulations impose limits on noise levels in order to avoid damage to occupants' hearing. Guidance concerning the practical implementation of the Regulations is included in the HSE publication *Reducing Noise at Work - Guidance on the Noise at Work Regulations 1989*(55). The Regulations and associated guidance do not address the slip and trip risk from noise. The *Control of Noise at Work Regulations 2005*(56) will shortly supersede the current Regulations.

CIBSE Guide A(23) provides Noise Ratings for a wide range of environments, eg offices, public buildings and hospitals etc. This data relates to the control of noise from building services in order to limit background noise. The data is not relevant to the avoidance of slips and trips as the noise levels are relatively low.

5.6 COMMISSIONING

To be effective in providing environment microclimate conditions that minimise the potential for slipping it is important that building services systems are properly commissioned. The consequences of deficient commissioning with regard to slip potential are numerous and include the following:

- Insufficient ventilation and air supply rates due to incorrectly balanced air distribution systems
- Insufficient ventilation and air supply rates due to incorrectly operating fans
- Low room air temperature due to incorrectly operating heater batteries in air handling units
- Low room air temperature due to incorrectly balanced hot water space heating systems

- Low room air temperature or insufficient ventilation due to incorrect configuration and operation of the control system
- Too high relative humidity levels due to incorrect operation of dehumidification equipment.

The incidence of trips may also be increased in buildings where the lighting system has been incorrectly commissioned.

Comprehensive guidance covering the commissioning of building services is provided by CIBSE and BSRIA. CIBSE guidance comprises the following Commissioning Codes:

- *Code A – Air distribution systems*(57)
- *Code B – Boilers*(58)
- *Code C – Automatic controls*(59)
- *Code L – Lighting*(60)
- *Code M – Management*(61)
- *Code R – Refrigeration systems*(62)
- *Code W – Water distribution*(63)

BSRIA's commissioning publications, which complement those produced by CIBSE, comprise:

- *Commissioning air systems in buildings – AG 3/89.3*(64)
- *Commissioning water systems in buildings – AG 2/89.3*(65)
- *Pre-commissioning cleaning of pipework systems – AG 1/01*(66)

Key commissioning considerations in order to provide microclimate conditions that minimise slip risk are:

- Air distribution systems
  - system cleanliness
  - fan checks
  - ductwork airtightness
  - regulation of airflow patternd/diffusion.

- Boilers
  - adequate exhaust discharge system
  - system activation, dry and live runs
  - safety interlocks
  - establishment of operation levels
  - boiler overheat test
  - confirmation of boiler controls operation.

- Water distribution systems
  - system flushing and cleaning
  - pump start checks
  - balancing and regulation of waterflow rates.

- Lighting
  - mechanical and electrical checks
  - confirmation of illuminance levels
  - correct operation of lighting controls and interaction with Building Management Systems (BMS).

- Controls

- correct installation of control equipment
- checking of control strategies
- confirmation of specific plant operation
- confirmation of interlocks and interfaces with other control systems.

5.7 MAINTENANCE

In order to ensure the continuing intended operation of building services equipment and help minimise the risk of slipping due to adverse microclimate conditions it is important that the equipment is properly inspected and maintained.

There are two main approaches to building services maintenance: time-based maintenance schedules and condition-based maintenance. In practice both approaches could be used in a building.

Time-based maintenance involves the undertaking of specific maintenance tasks at pre-defined time intervals. The Heating and Ventilating Contractors' Association (HVCA) provides comprehensive time-based maintenance schedules in a number of publications[(67)]. Those most directly relevant to the avoidance of slips through the correct operation of building services systems are:

Standard maintenance specification for mechanical services in buildings
Vol 1 – Heating and pipework systems
Vol 2 – Ventilation and air conditioning
Vol 4 – Ancillaries, plumbing and sewerage

As an alternative BSRIA's publication *Business-Focused Maintenance*[(68)] provides guidance and sample maintenance schedules for a range of building services systems and equipment. Those most relevant to the avoidance of slip potential cover the following:

- Boilers
- Valves
- Pumps
- Heat exchangers
- Drive elements
- Fans
- Air handling units.

The second main approach to maintenance, condition-based maintenance, involves the monitoring and analysis of parameters that can give an indication of the "health" of the item of equipment. This in turn can give an indication of whether the item of equipment is likely to fail. Examples of condition-based maintenance techniques are:

- Vibration analysis. This can be used to detect faults such as bearing degradation/lubrication degradation/imbalance in pumps and fans serving heating and ventilation systems.

- Acoustic emission. This can be used to detect faults such as bearing degradation/lubrication degradation affecting pumps, fans and motors along with cavitation in pumps.

- Power quality. This can be used to detect faults such as harmonic current overload in cables supplying electrical power to equipment such as fan and pump motors.

- Wear and oil analysis. This can be used to detect faults such as bearing and lubricant degradation in fans and pumps.

- Thermography. This can be used to detect faults such as blockages and poor heat transfer in underfloor heating systems and bearing degradation/windings overheating in fan and pump motors.

The above examples rely on the use of specialist monitoring and analysis equipment, however a building's BMS can also play a role in condition-based monitoring. For example the condition of a fan can be monitored to detect the following sources of fault:

- Bearing/lubrication – monitoring speed/temperature
- Fan belt – monitoring differential pressure/velocity/motor current
- Misalignment/imbalance – monitoring speed
- Air-side fouling – monitoring differential pressure/flow/motor current/speed.

Guidance concerning the use of condition-based maintenance is provided in the BSRIA publication *Condition Based Maintenance – An evaluation guide for building services*(69)

In many circumstances a building and its associated services may have undergone little if any planned preventative maintenance. If the building has been recently purchased or let the building operator may want to assess the condition of the building services. If this is the case condition surveys can be performed. Guidance concerning such surveys is provided in the BSRIA publication *Condition Survey of Building Services*(70). The publication includes a number of condition survey checklist. Those most related to the provision of microclimate conditions include:

- Boilers, heating and hot water systems
- Ventilation and air conditioning systems
- Control systems
- Lighting systems.

6 REVIEW OF BUILDING SERVICES AS A RISK FACTOR

6.1 GENERAL

While providing a means of limiting and/or removing condensation from floor surfaces and hence reducing slip potential building services can also, under certain circumstances, act as a risk factor. Where fluids leak, for example from pipework, the resulting contamination on a floor surface will present a slip risk. In addition, where the leakage is substantial the leaked fluid (usually water) will evaporate and raise the level of internal humidity. This in turn can cause a condensation risk if the humid air is transferred to an adjoining area.

Condensation on the surface of building services components can present a risk if the condensation drips onto a floor surface.

The following outlines some of the potential risks along with the respective considerations and strategies to alleviate the risk.

6.2 PIPEWORK

The Heating and Ventilating Contractors' Association (HVCA) publish guidance entitled *Installation and Testing of Pipework Systems (TR/20)*(71). Published in several parts the guidance covers the following:

- Low temperature hot water heating
- Medium temperature hot water heating
- High temperature hot water heating
- Hot water service
- Cold water service
- Chilled water
- Condenser and cooling water
- Steam and condensate
- Natural gas
- Oil

The guides provide comprehensive guidance, for example, the guide concerning pipework for low temperature heating addresses the following issues:

- Material and jointing methods
- Pipework construction and assembly
- Accessories and pipeline ancillaries (eg valves, strainers, test points etc)
- Thermal insulation
- Flushing, cleaning and water treatment
- Testing

Concerning testing the guide makes reference to another HVCA publication – *Guide to Good Practice for Site Pressure Testing of Pipework (TR/6)*(72).

BS 5422:2001: Method for specifying thermal insulating materials for pipes, tanks, vessels, ductwork and equipment operating within the temperature range –40^{o}C to +700^{o}C (73) provides minimum insulation thickness for condensation control on pipework carrying chilled and cold water supplies.

6.3 DUCTWORK AND AIR TERMINALS

BS 5422 also provides minimum insulation thickness for condensation control on ductwork carrying chilled air in ambient conditions.

For un-insulated ducts carrying cold air originating from the exterior Liu et al[(74)] discusses the use of a moisture-absorbent coating to prevent the dripping of condensate.

Kahirajima et al[(75)] reports on concerns that the use of cold air distribution systems can lead to the formation of surface condensation on air outlets. Under the test conditions used the paper concludes that supply air temperatures of 11°C and above will prevent the formation of condensation.

Shih-Cheng et al[(76)] discusses the use of computational fluid dynamics (CFD) to study the risk of condensation on ceiling diffusers used with a cold air distribution system. The paper states that with the modelled multi-cone circular diffuser the risk of surface condensation increases as the supply flow rate increases and that the influence of the cone lips on airflow diffusion is very significant. The paper proposes modifications to the multi-cone circular diffuser to prevent the occurrence of surface condensation.

6.4 CHILLED CEILINGS/BEAMS

Chilled ceilings and beams are becoming increasingly popular as a means of removing heat from rooms (typically commercial offices). As their name suggests the ceilings/beams are chilled by a cooling medium, usually water. Because the surface temperature is relatively low (typically 14°C) a risk of condensation forming can occur when the relative humidity of the indoor air is high. Martin[(77)] discusses the results of a series of laboratory tests aimed at assessing the efficacy of different control strategies in avoiding condensation. The control strategies tested were:

Test A: Plant shutdown on condensation detection: on the detection of any condensation the air handling unit and/or chilled ceiling were immediately switched off. Condensation was sensed using a condensation detector.

Test B: Maintaining a constant temperature differential between supply air and test cell (air was supplied at temperatures below that of the test cell with a constant supply air relative humidity and initial room condition).

Test C: Maintaining a constant temperature differential between the chilled water and the room dewpoint (the dew point temperature was calculated from the zone's temperature and relative humidity sensors).

Test D: Dehumidifying the supply air (the supply air humidity was controlled to ensure the differential between the test cell dew point and the chilled water temperature was maintained with a constant supply air temperature and initial room condition).

The paper concludes that the tests demonstrated that control of the supply air relative humidity to maintain a low dew point (Test D) in the room is the most effective method of avoiding condensation. High latent loads and sensible heat loads can be contained sufficiently to avoid condensation formation.

CIBSE *Guide B2 – Ventilation and air conditioning*[(33)] recommends that condensation detection should always be incorporated into the chilled ceiling/beam control system. The guide states that the condensation detection should be by direct dew point sensing using a device clamped to the pipework and indicates that it is not practical to measure independently the room temperature and humidity in order to calculate dew point. The inherent lack of accuracy of most humidistats makes their use for this purpose impractical. The guide recommends that when condensation is detected either the chilled water supply temperature should be ramped up one degree at a time to ride above the dew point or the chilled water should be shut off completely and an alarm raised on the building's Building Management System (BMS).

6.5 DRAINAGE ISSUES

For general foul water below ground drainage it is important that the drains have enough capacity to carry the design flow; if not surcharging will occur which in turn will present a risk of slipping on contaminated floor surfaces. This risk can be avoided by designing the drainage system in accordance with *Approved Document H1 – Foul water Drainage*(78). The requirements of *H1* can also be met by following the design guidance provided in:

- *BS EN 752 – Parts 3,4 and 6*(81)
- *BS EN 1295*(82)
- *BS EN 1610*(83)
- *BS EN 12056 – Part 2*(84)

BSRIA's publication *Design Checks for Public Health*(80) provides design checks for foul water drainage systems.

Commercial kitchens and food service areas are high risk working environments from the perspective of slips and trips. The *HSE Catering Information Sheet No 6*(4) recommends the use of drainage channels to carry water, steam drips and waste away from kitchen equipment. However it is important to ensure that any drainage from the kitchen is free to do so and not hindered in order to prevent flooding.

Approved Document H1 – Foul water drainage requires that grease separators complying with *BS EN 1825*(79) are installed in all commercial kitchens. These are intended to prevent the drainage system being blocked by build up of kitchen grease.

BSRIA's publication *Design Checks for Public Health* provides design checks for commercial kitchen drainage. Guidance provided includes the following:

- Drainage pipework – robustness and gradient
- Drainage stacks
- Requirement for traps
- Sizing, location and installation of grease separators.

7 CONCLUSIONS

The risk of slipping on floor surfaces is primarily a function of the floor surface characteristics, presence of fluids on the floor surface, the type of activities performed in the building along with occupants' footwear.

The potential for slipping will be increased where condensation either forms directly on the floor surface or forms on other surfaces and then flows or drips onto the floor surface. The risk of slipping will also be increased where contamination is deposited on the floor surface (eg rainwater on the soles of footwear).

Where condensation or contamination does occur the risk of slipping will be reduced if the water is evaporated quickly.

Internal relative humidity, internal surface temperatures and ventilation influence the formation and removal of condensation and contamination. These factors are in turn influenced by the provision of building services, namely heating, ventilation and air conditioning systems.

In some built environments the floor surface will effectively negate slip potential. This is especially the case in office type environments that are carpeted. However, in many situations the use of smooth hard floor surfaces will present a serious slip risk. This is especially the case where condensation or contamination is also possible. In this type of situation building services can provide a role in minimising the slip risk. Situations that present a high risk of slipping and where building services can help include the following:

- Entrances and lobby areas of offices and public buildings. These areas often have smooth hard floor surfaces. In addition the risk of contamination is high from rainwater brought into the building on the soles of footwear along with wet surfaces resulting from floor cleaning. In this type of scenario building services systems such as underfloor heating and/or enhanced airflow can help evaporate contamination and also prevent condensation. Other approaches such as radiant heating may also be appropriate.

- Washroom and toilet facilities in commercial and public buildings. As with the above situation, contamination of the floor surface could be evaporated using underfloor heating and/or enhanced airflow.

- Commercial kitchens and food processing/preparation areas. This type of working environment presents a very high risk of slipping compared to other industries. While suitable floor surfaces and footwear along with adequate cleaning regimes present the primary means of limiting the risk of slipping, building services an also provide a role. In this type of situation the use of underfloor heating is unlikely to be acceptable given the high ambient air temperatures in the work areas, however enhanced ventilation and air movement could be used to evaporate many forms of contamination.

At present the guidance provided by the HSE and CIRIA on identifying and controlling the risk of slipping does not adequately address the role played by microclimatic influences and building services. Design engineers and architects along with other parties such as clients and building owners/operators require practical guidance on how building services can be used to adequately control microclimatic conditions in order to minimise the risk of slipping.

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