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THE EFFECTS OF RADIANT COOLING VERSUS CONVECTIVE COOLING ON HUMAN EYE TEAR FILM STABILITY AND BLINKING RATE

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SUMMARY

The effect of indoor temperature, radiant and convective cooling on tear film stability and eye blink frequency was examined. 24 human subjects were exposed to the non-uniform environment generated by localised chilled beam and a chilled ceiling combined with overhead mixing ventilation. The subjects participated in four two-hour experiments. The room air temperature was kept at 26 °C or 28 °C. Tear film samples were collected after 30 min of acclimatisation and at the end of the exposures. Eye blinking frequency was analysed for the first and last 15 min of each exposure. The tear film stability decreased as the temperature increased. The highest number of subjects with unchanged or improved tear film quality was observed with the localised chilled beam at 26 °C. A trend was found between subjects who reported eye irritation and had a bad tear film quality.

INTRODUCTION

Eye irritation is a common complaint of occupants in office environments, where intensive computer work can result in dry spot formation and eye dryness caused by pre-corneal tear film damage (Wolkoff, et al., 2003). The ocular surface of the eye is covered by tear film, which prevents water evaporation from the surface and keeps it moist. It is comprised of three layers: the lipid, the aqueous and the mucin layers (Wolkoff, et al., 2003). The tear film is constructed from a complex interaction during the blink process among the eyelids, the mucosal surface and the molecules forming the tear film itself. The tear film creates almost perfectly smooth optical surface to provide refractive media for the light. It also transports oxygen from the surrounding air to the cornea, protects the eye against environmental exposure, bacterial growth and injuries of the ocular surface and washes away debris and irritants.

Blinking is important for the human eye since it maintains a healthy ocular surface and defends the eye from environmental exposure (Tsubota & Nakamori, 1995). Depending on the activity the eye blink frequency (BF) may differ. A normal eye at rest has BF from 10.5 up to 32.5 blinks/min on average. When people focus on a specific task involving visual alertness, the BF will most likely drop. Studies have shown that, when reading the BF decreases to an average of 4.5 blinks/min, and will most likely occur when changing text lines (Karson, et al., 1981). It is seen, that when the face is exposed to air velocities higher than 0.5

m/s, the BF increases but is repressed during visual tasks (Carmen, et al., 1999). During blinking the tear film is refreshed and this avoids drying and break-up on eye surface. An increase in air temperature and relative humidity decreases the tear film evaporation and thus the blink rate, while elevated air velocity increases the evaporation resulting in increase of eye blink rate (Wolkoff, et al., 2003). Studies with personal ventilation (PV) providing cooler airflow toward the face show that the tear film stability was improved compared to the same warm environment but without PV (Melikov, et al., 2013). The subjects were provided with control over the air flow rate and direction, therefore they may have been able to avoid eye discomfort (Melikov 2004).

Local chilled beam (LCB) generates local micro-environment at each workstation under the individual control of occupant (Uth et al. 2014). Convective heat exchange between the body and the surrounding environment plays important role. The LCB aims at elevated velocities and lower temperatures at workstation. The air is directed downwards over the face (head) of the occupant seated below. Chilled ceiling combined with mixing ventilation is used to generate indoor environment at reduced energy consumption. In this case radiant heat exchange between the body and the surrounding is important. The effect of radiant and convective cooling on eye symptoms is not investigated and needs to be studied.

In this paper the impact of the thermal environment generated by LCB and by chilled beam with mixing ventilation on eye comfort (objectively measured – eye blink frequency and tear film stability, and subjectively reported – eye dryness and irritation) was studied and compared

METHODOLOGIES

Twenty-four subjects (12 male and 12 female subjects) participated in four experiments. Each subject was exposed to the thermal environment generated either by the localized chilled beam (LCB) or by the chilled ceiling combined with mixing ventilation system (CCMV) under two summer conditions (26 °C and 28 °C). The exposure was randomized. The experiments were performed in a climate chamber (4.2 m x 4.12 m x 3.1 m) equipped as a single office with three workstations and one laptop (Figure 1). Five heated radiant water panels on one wall together with five heated electrical foils installed in half the room floor were used to simulate direct solar gains from windows. The total internal heat load in the room was 56 W/m² (including the heat load from the subject). The main workstation (WS1) was placed near the window (0.65 m away). Another workstation (WS3) was in the opposite side of the room away from the simulated window. A third workstation (WS2) was in the opposite corner to WS3. It consisted of a bookshelf and was used to simulate typical transient increased activity of occupant in the office. The room air temperature around WS1 was kept at either 26 °C or 28 °C. The air supplied by the mixing ventilation (two ceiling slot diffusers) was kept at 13 L/s and 16 °C. The LCB mounted above WS1 to create a cooler zone around the occupant when sitting at the main workstation. The maximum primary air supplied from the LCB was also 13 L/s and 16 °C but the subject could control it down to 6 L/s. The total exposure time was 2 hours, with additional half an hour of acclimatisation before the exposure. Subjects were performing three different types of work tasks. During the first 30 min subjects sat at WS1 where they performed office work (computerized tasks), then they moved for 10 min at WS3 (light office work), then back to WS1 for 30 min, followed by 20 min at WS2 performing office work at increased activity (1.1-1.4 Met) and at the end 30 min at WS1 (Table 1). As an energy saving strategy, subjects were instructed to reduce the

primary air flow rate supplied by the LCB to 6 L/s during the 20 min period while at WS2, resulting in increase of air temperature inside the room.

Table 1. Experiment procedure.

Activity	Met	Duration [min]	Placement
Acclimatisation	1.1	30	Chamber 6
Desk Work	1.1	30	Workstation #1
Desk work	1.1	10	Workstation #3
Desk Work	1.1	30	Workstation #1
Increased activity	1.1-1.4	20	Workstation #2
Desk Work	1.1	30	Workstation #1

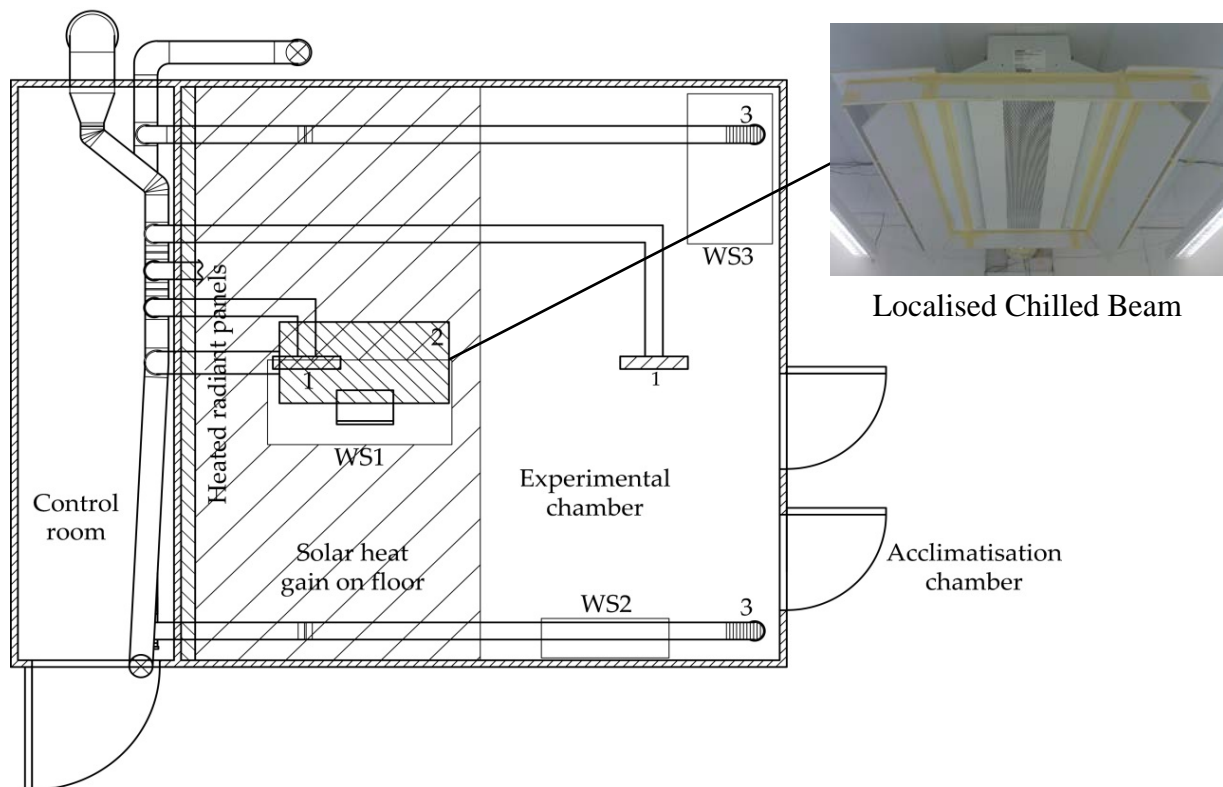


Figure 1. Experimental chamber, 1) mixing supply air ceiling diffusers, 2) localized chilled beam, 3) ceiling mounted exhaust.

Eye dryness was reported by the subjects with the scale from 0 (no dryness) to 100 (overwhelming dryness) at the beginning and end of their stay at each workstation. Tear film samples were taken to assess the integrity and quality of the tear film after 30 min of acclimatisation, before the exposure, and again at the end of the 2 hours of exposure at WS1. Each subject sampled their own tear secrets based on instructions given prior to the experiments. For each test, subjects were provided with a kit consisting of a mirror, a microscope glass slide, glass rod and sterile wipes with isopropyl alcohol. The samples were taken from under the lower eyelid and then smeared onto the microscope slide. The crystallisation patterns were examined under microscope. Pictures were then taken with a connected to the microscope camera. The samples were divided into four quality grades defined by Rolando (1984) (Figure 2), corresponding to the density and branching pattern of the fern/crystals. Grade I and II corresponded to healthy eyes, while III and IV to unhealthy

eyes. The tear film grade analysis was performed independently by 4 evaluators. After the individual evaluation the evaluators met and finalised the grading

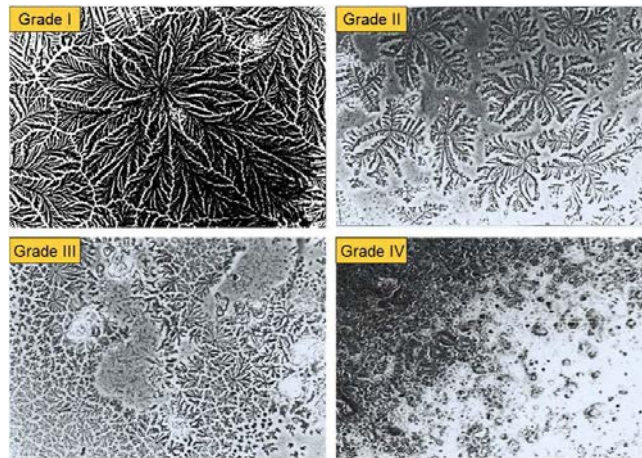


Figure 2. Classification of tear mucus quality in four categories (Rolando (1984)s).

Web-cameras were used to record the face of the subjects during their stay at the main WS1. The camera attached to the laptop screen allowed observation of the subjects' face. For the analysis of the eye blinking frequency, the number of eye blinks were counted and compared for the first 15 minutes of the exposure and for the last 15 minutes of the total exposure. Video recording was not obtained for all 24 subjects under all four conditions. In some cases the subjects were sitting out of the camera range, which made it impossible to clearly see their eyes. Also in some cases it was observed that test subjects were dozing, which made it difficult to observe a precise blink frequency in this 15 minute period. VLC media player was used to watch the recorded videos, and was possible to increase the speed of the video. The videos recorded were watched at 1.5 times increased speed from the normal recorded speed. The increased speed does not affect the accuracy of the blink rate counting (Melikov et al, 2011).

RESULTS AND DISCUSSION

The tear film samples collected from the subjects showed that 50-58 % of the subjects had a tear film quality of Grade II at the beginning and at the end of the exposure 46-67 % of the subjects (Table 2, Figure 3).

Table 2. Number of subjects with the four categories of tear film quality during the four tested conditions.

Tear film quality	LCB26		LCB28		CCMV26		CCMV28	
	Start	End	Start	End	Start	End	Start	End
Total Grade 1	4	4	4	2	4	4	5	4
Total Grade 2	12	16	12	12	14	11	12	14
Total Grade 3	4	3	6	6	5	8	5	4
Total Grade 4	4	1	2	4	1	1	1	1

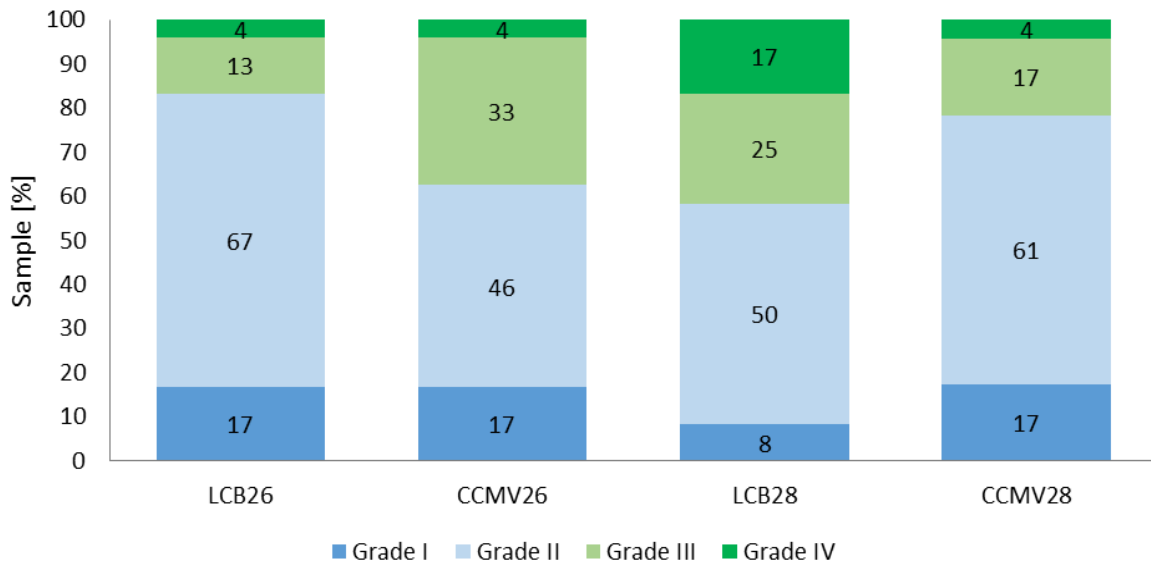


Figure 3. Percentage (number – given in the bars) of tear-film samples in the four quality grades after 2 hours to each experimental condition.

The change in tear film quality from the beginning to the end of the exposure was affected by the indoor environment. Most test subjects' tear film quality remained unchanged (Figure 4) throughout the whole exposure under all four tested conditions (LCB and CCMV at 26 °C and 28 °C). LCB at 26 °C showed the best impact of the generated environment on the quality of the tear film (Figure 4). This condition contained the largest number of subjects with unchanged and improved tear film quality. However, for the warmer environment of 28 °C, the CCMV had the least number of people with decrease in tear film quality. Under LCB28 the tear film quality decreased the most (50 % decrease). When comparing the two systems with regards to temperature difference the elevated temperature resulted in decreased tear film quality. However, this was not the case for the CCMV (Figure 4).

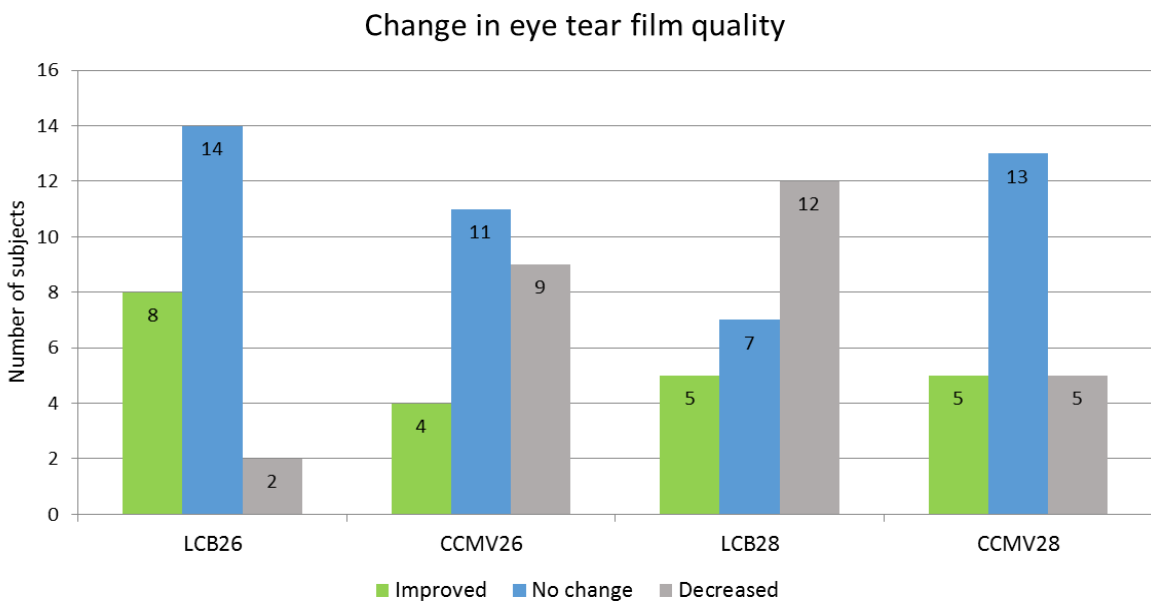


Figure 4. Tear film quality change during the exposure.

The majority, 67-75 %, of the subjects started with grade I-II and ended with the same grade (58-83 %), Figure 5. This corresponds well with the eye irritation votes given by the subjects during the experiment (Figure 6), where approximately the same number of subjects voted eye irritation as the number of subjects with tear film grade III and IV.

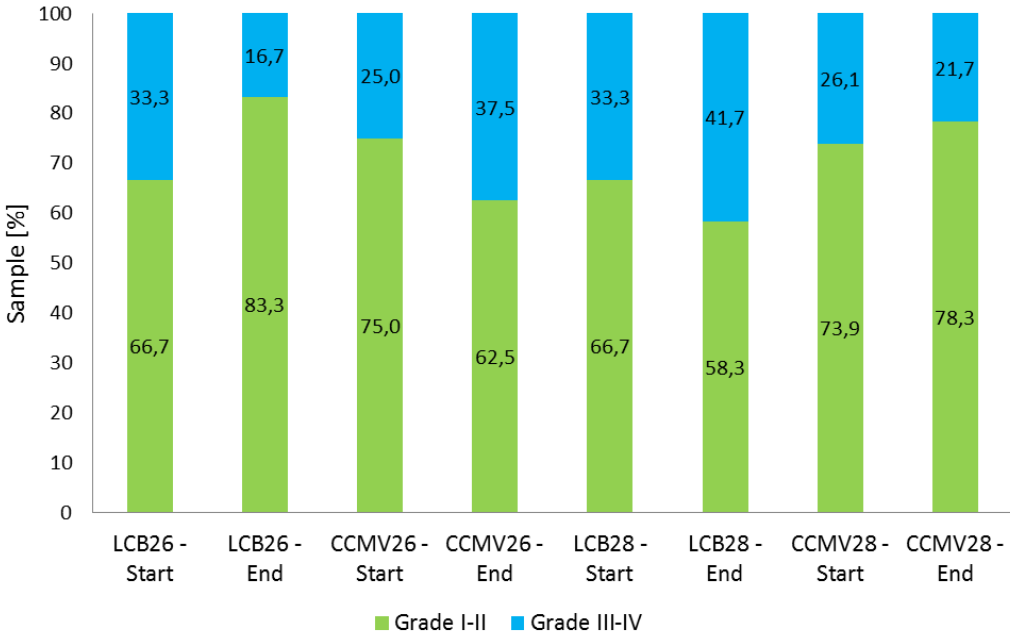


Figure 5. Subject division in tear film grades I-II & III-IV after 2 hours of exposure

Eye irritation and/or dryness can be a sign for reduced tear film quality. The number of subjects voting eye irritation was generally the same for all four conditions (Figure 6). A trend between eye irritation and tear film quality was found, i.e. subjects reporting eye irritation had a lower tear film quality than the ones without eye irritation (Figure 6).

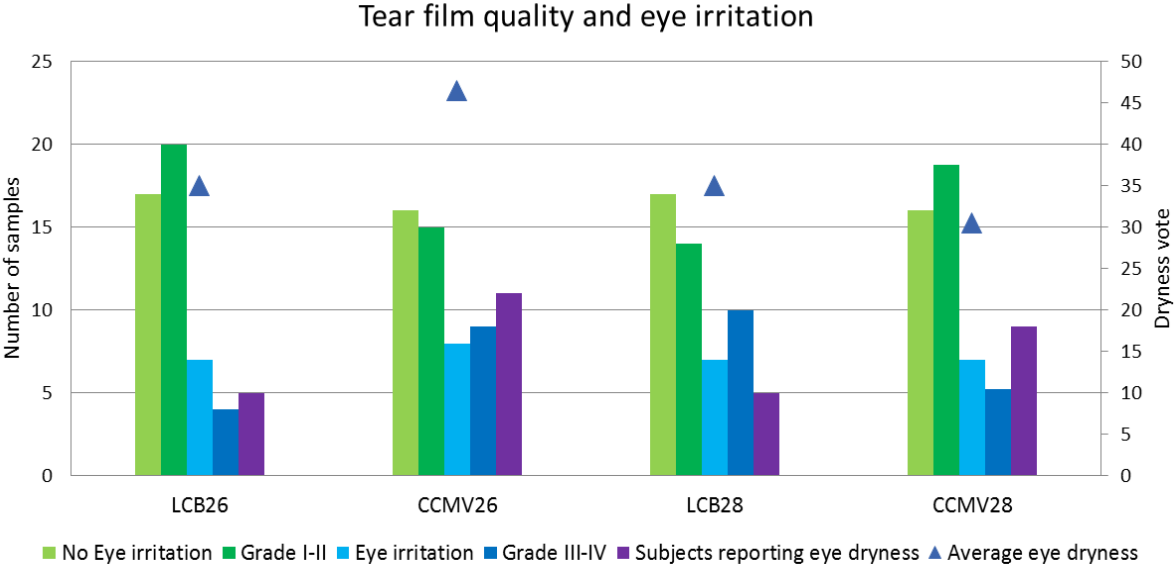


Figure 6. Tear film quality, eye irritation and reporting eye dryness and votes at the end of the 2 hour exposure. Dryness voted: 0 (no dryness) to 100 (overwhelming dryness).

It was observed that subjected blinked less at the end of the exposure with the LCB at 26 °C and CCMV at 28 °C. The average blink frequency was calculated from the total number of blinks for all subjects during the two 15 minute periods. The average blink frequency was very similar to what earlier studies show (Carmen et al., 1999): a decrease to 4.5 blinks/min when the subject was focused on a specific task. However, within the condition of LCB28, the BF during the first 15 minutes was significantly higher, almost doubled. The decrease in BF can decrease the tear film quality due to reduced refreshing of the tear film. This assumption corresponds well with the found decrease in tear film quality for LCB28 (Figure 4) for 50 % of the subjects.

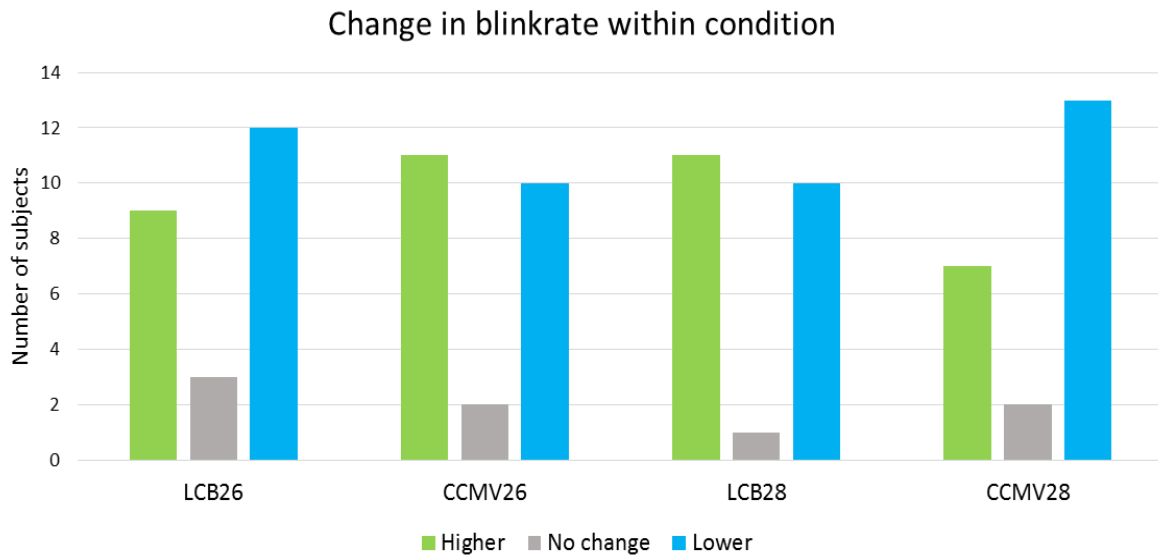


Figure 7. Number of subjects with increase, decrease and no change in blink frequency during the exposure to the four condition (increase or decrease from first 15 minutes to last 15 minutes)

The studies of Wolkoff (2008) and Melikov et al. (2012) reported that the tear film stability was negatively affected by increase in temperature. The results of the present study confirm the previous findings that the tear film quality decreases as the temperature increases for LCB i.e. the extra air movement around the face, convective cooling. The condition with LCB26 at WS1 had the largest number of subjects with unchanged or improved tear film quality. High number of subjects with a decrease in tear film stability at the end of the exposure at condition LCB28 can arguably be due to the significant decrease in the average BF, which also is a conclusion of other studies (Wolkoff, 2008). The tear film stability was affected by convection, i.e. air speed measured in 1.1 m above the floor (in location corresponding to the subjects' position) was respectively 0.19 m/s and 0.11 m/s for 26 °C and 28 °C, combined with temperature difference between room air and eye surface temperature. No previous studies have been done in relation to tear film stability and radiant cooling. For the present study, the tear film stability was decreased under lower temperatures with the CCMV system as a result from the higher heat exchange between the room air and the cornea i.e. a larger temperature gradient gives faster evaporation and thereby lower tears film stability (-0.5 K for CCMV26). Figure 6 show a clear trend between tear film quality and reported eye irritation: the number of votes of eye irritation was similar to the number of tear film samples graded as III-IV (bad quality) and vice versa. This was true for the two tested systems.

CONCLUSIONS

The following conclusions can be made:

- Tear film quality decreased with increase in temperature for the convective cooling system, (LCB) while this was opposite for the radiant cooling system (CCMV). The elevated air flow rate from the LCB decreased the negative effects of high temperature on tear film quality for the condition at 26 °C. The highest number of subjects with unchanged or improved tear film quality was observed with LCB26.
- Subjects had lower blink frequency at end of the exposure with the LCB at 26 °C and with the CCMV at 28 °C. A positive trend between the tear film quality and the eye blink frequency was observed. The reduction in eye blink frequency reduced the tear film quality as the refreshing of tear film was reduced.
- A trend between eye irritation and tear film quality was found, i.e. subjects reporting eye irritation had a lower tear film quality than the ones without eye irritation

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