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An experimental study investigating differences in acclimatization capacity and thermal preference between university students and older workers

Alice Caporale[1*], *Luca* Zaniboni[2], *Pawel* Wargocki[2], and *Cristina* Mora[1]

[1]Industrial Engineering Department (DIN), University of Bologna, Bologna, Italy
[2]International Centre for Indoor Environment and Energy, Department of Environmental and Resource Engineering, Technical University of Denmark (DTU), Copenhagen, Denmark

Abstract. This experimental study aims to test thermal response and the ability to acclimatize during thermal discomfort conditions of different age groups. Experiments were conducted in late summer with thirteen participants, including university students and older workers, exposed in a climate chamber to a temperature increasing from 22°C to 28°C and decreasing from 22°C to 16°C, at a rate of 3.5K/h. Participants adjusted their clothing to stay thermally neutral at 22°C. After that, they were not allowed to change clothing during temperature ramps. Subjects rated their thermal comfort, preference, and acceptability during increasing and decreasing temperature ramps. Skin temperature was measured in two points to monitor the processes of vasoconstriction. Older workers showed higher vasoconstriction in both ramps due to more rapid and more significant cooling of extremities. However, older workers showed a higher tolerance for thermal discomfort conditions during the cold ramp, suggesting that they might physically suffer more from thermal discomfort but be less aware of it. During the hot ramp, older workers showed greater variability in psychological response, although comparable mean values suggest that thermal neutrality might remain similar with increasing age. For this reason, the percentage of dissatisfied among older workers could be different despite similar neutral temperatures. The results highlight the need to extend the study with comparable experiments to collect further data on older workers' acclimatization capacity and thermal preferences.

1 Introduction

Since people spend a significant part of their daytime inside buildings, studying the impact of Indoor Environmental Quality (IEQ) factors on them is essential [1]. First, to ensure the occupant's comfort and, as a second effect, to limit the buildings' energy expenditure [2]. Among IEQ factors, thermal comfort proved to have a significant influence on occupants' comfort and productivity [3, 4].

ANSI and ASHRAE standard 55 defined *thermal comfort* as the condition of mind that expresses satisfaction with the thermal environment. The indices used to evaluate thermal comfort derive from a theoretical approach applying the energy balance equation to the human body [5].

In 1960, Povl Ole Fanger proposed the Predicted Mean Vote (PMV) methodology to predict the average thermal sensation of large populations on a seven-point thermal sensation scale [6]. Additionally, the Predicted Percentage of Dissatisfied (PPD) estimates the percentage of occupants not feeling satisfied at a certain thermal condition. In fact, even in optimal conditions (PMV = 0), there is a percentage (PPD = 5 %) of subjects who consider the microclimatic conditions unsatisfactory. Moreover, literature studies reported the presence of substantial disparities when comparing the PMV values to the actual thermal sensation reported by occupants in real-case scenarios set in offices or other production environments [7, 8, 9, 10]. According to the 2022 study by Arakawa and Martins, the inconsistency between the model's results and the registered thermal sensation relates to the model's inability to incorporate demographic characteristics (e.g., age, gender, and nationality) [11].

When considering the age factor, the 2019 study of Isa and Atim highlights the decline in thermoregulatory response as one of the main factors determining the reduced environmental tolerance in older workers (45-65 years old) [12]. On the one hand, physiological changes in the cardiovascular and respiratory systems (after the age of 30 years old) can reduce the effectiveness of the body's thermo-regulatory function, limiting tolerance to environmental stresses [13]. On the other hand, the inability of individuals to adapt to uncomfortable thermal environments can in cardiovascular diseases [14]. Fanger's model assumes that older workers (45-65 years old) thermal response is similar to the one provided by young adults, whose comfort temperature in winter is around 22 °C with 1 clo and in summer around 24 °C with 0.5 clo [6]. However, the literature suggests that the elderly (age 65 and over)

* Corresponding author: alice.caporale2@unibo.it

prefer higher room temperatures than younger people [15, 16] but lacks studies quantifying the thermal preferences of older workers and their ability to acclimatize in thermal discomfort conditions.

Adequately adjusting the workplace temperature would be crucial to protect workers' health.

In this framework, the present experimental study will help understanding how the thermal needs of older workers differ from students', assessing their response to thermal discomfort conditions during two temperature ramps through the evaluation of psychological responses and physiological correlates.

2 Experimental methods

In the current study, seven college-age students and six older workers were exposed to increasing and decreasing temperature ramps at the rate of 3.5 K/h, after being allowed to modify their clothing insulation to be thermally neutral at 22 °C. ASHRAE requirements in terms of maximum operative temperature change allowed (i.e., 2.2 K/h) were not met, since the study aimed to test how participants react to thermal discomfort conditions [5]. Moreover, only male subjects participated in the experiment to eliminate the gender factor as a variable possibly influencing the results. It is planned to repeat the experiment with a larger sample, including both male and female participants.

2.1 Climate chamber

The experiments took place between mid-September and October 2022 in a climate chamber (5 m [16.4 ft] wide, 6 m [19.7 ft] long, and 2.5 m [8.2 ft] high) at the laboratory of the Department of Environmental and Resource Engineering at Technical University of Denmark. The chamber was developed to accurately control the thermal environment [17] and is located in an indoor lab with a HVAC system. The inside wall layer of the climate chamber is made of vinyl sheets separated from the solid outer walls by an air gap 1.6 cm thick approximately. This space allows mean radiant temperature to be always equal to air temperature, even during thermal transitions.

2.2 Participants

A total number of thirteen subjects (seven university students aged 20–28 and six older adults aged 45-60) participated in the experimental sessions. All subjects were men, healthy, normotensive, and not undergoing any treatment that might alter the cardiovascular or thermoregulatory responses to the temperature changes. Before the experiment started, each participant signed the consent form to process personal data.

During each session, up to eight subjects attended the experiment, sitting in the chamber at separate workplaces with a desk and a chair. Each participant worked on a computer during the experiment. Each subject participated in the two sessions on two different days of the same week, chosen randomly to minimize biases caused by order of exposure.

2.3 Measurements

Environmental and physiological parameters were recorded in the experiment. The environmental parameters included air temperature, globe temperature and air relative humidity. These quantities were detected at 30-second intervals, by means of two sensor stations positioned in the middle of the two long sides of the chamber. The sensors stations comprised HOBO sensors to measure air temperature and humidity. Moreover, we used grey bulb sensors (0.04 m diameter) to calculate the operative temperature according to UNI EN ISO 7726:2002 [18]. The sensors were positioned at a height of 0.6 meters, to resemble the position of seated participants according to ASHRAE Standard 55 [5]. Moreover, Sessler's method of estimating skin blood flow (SkBF) was used to determine vasoconstriction thresholds (triggering core temperature) [19, 20].

Measurements of skin temperature were taken at 30-second intervals on the forearm ($T_{sk\ forearm}$) and index finger ($T_{sk\ finger}$) by means of iButton temperature loggers. This allowed vasoconstriction/vasodilation to be characterized by the temperature difference calculated by means of the following equation (1):

$$T_{sk\text{-}diff} = T_{sk\ forearm} - T_{sk\ finger} \quad (1)$$

The accuracies of the measuring instrumentation were 0.35 K (0.63 °F) (air and globe temperature), 2.5 % (relative humidity), and 0.1 °C (skin temperature).

2.4 Subjective questionnaires

While monitoring environmental and physiological parameters, participants were asked to complete their subjective thermal responses four times per session. The psychological responses involved the thermal comfort vote (TCV), thermal preference vote (TPV), and thermal acceptability vote (TAV).

Figure 1 represents the thermal response scales developed in accordance with UNI EN ISO 10551:2019 [21].

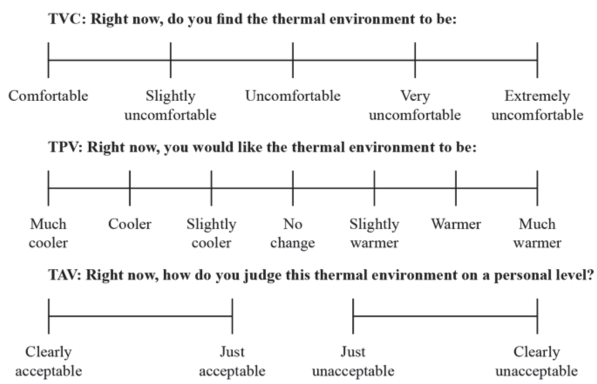

Fig. 1. Scales used to assess thermal comfort, thermal preference, and thermal acceptability, according to UNI EN ISO 10551:2019.

2.5 Experimental procedure

Figure 2 represents the main steps of warm ramp and cold ramp exposures used in the experiment.

In both sessions, subjects were initially exposed at 22 °C with 40 % humidity for one hour, to allow their adaptation to the starting condition. Participants were allowed to modify their clothing to achieve thermal neutrality (i.e., feeling neither hot nor cold) after the acclimatization time. This was allowed only during the first session, with subjects being asked to maintain the same chosen clothing also during the following session.

Subjects were able to choose between three garments (long-sleeved T-shirt, light jumper, or thick jumper) that differed slightly in insulation (0.20-0.35 clo) [22] but not sleeve length. This permitted to obtain comparable skin surface temperature results. It is important to specify that the initial clothing adjustment was not aimed at maintaining comfort conditions during the entire ramp duration, as the purpose of the study was to evaluate psychological and physiological responses to discomfort conditions as a function of the subjects' age.

After the acclimatization period, participants underwent two temperature ramps at the rate of 3.5K/h from 22 °C to 28 °C and from 22 °C to 16 °C, respectively.

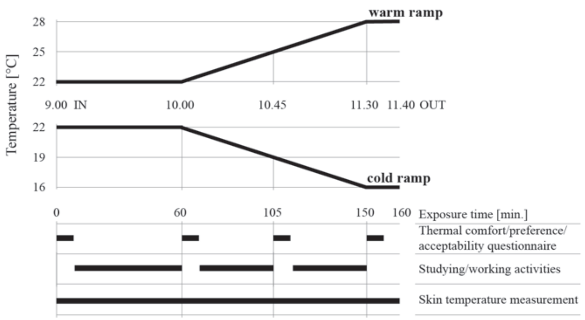

Fig. 2. Experimental procedure

Both during the warm ramp and the cold ramp, participants were asked to fill in the same questionnaire four times: (1) as soon as they entered the climatic chamber; (2) after one hour, just before the ramp began; (3) halfway through the ramp; (4) at the end of the ramp before leaving the climatic chamber.

3 Results and discussion

3.1 Cold ramp

The trend in skin temperature difference characterizing vasoconstriction ($T_{sk\text{-}diff}$) of older workers (a) and students (b) during the cold ramp is represented in Figure 3. It can be noticed that the trend in the two graphs is similar, except for the two peaks in the workers' graph, when they enter the thermal chamber (22 °C) and reach 16 °C. These peaks and the resulting standard deviation highlight a higher variability in the physiological response of older workers' sample (3a). Moreover, the initial peak suggests that workers were uncomfortable entering the chamber because it was not meeting their neutrality condition. In both samples, vasoconstriction values were close to zero during to the first adaptation hour, then rising again as the chamber temperature decreased.

In the case of students (3b), the growth of $T_{sk\text{-}diff}$ values is due to the slowing down of metabolism, aimed at maintaining the initial stationary comfort condition. The effect of this process is a decrease of the temperature at the extremities (fingers). In the case of older workers (3a), the initial vasoconstriction peak seems to have been compensated by the possibility to adjust the clothing level.

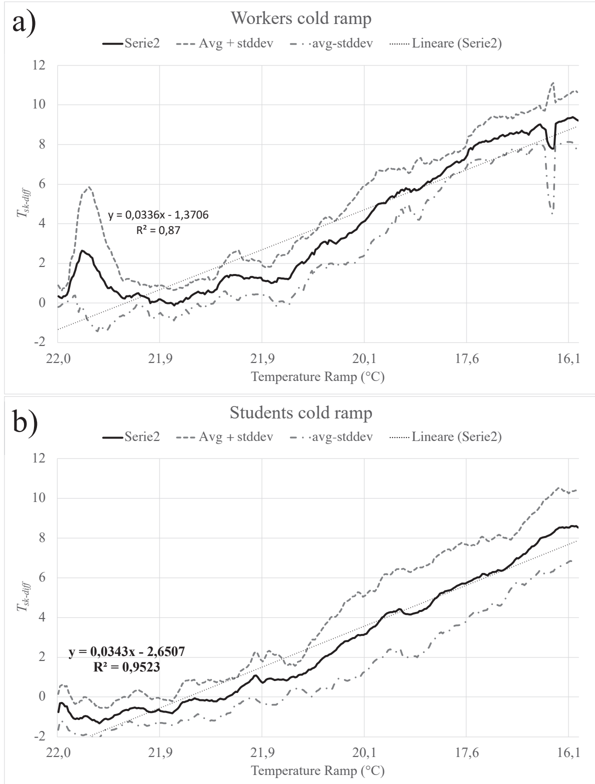

Fig. 3. Trend in $T_{sk\text{-}diff}$ value for older workers (a) and students (b) during the cold ramp.

At 19 °C and 16 °C, students show a lower $T_{sk\text{-}diff}$ than workers. At 19°C, the value for students is 4, while for workers it is close to 6. At 16°C, the value for students is 8.3 and 9 for workers.

Figure 4, which represents the TCV of workers and students compared during the cold ramp, shows contrasting results compared to the physiological response observed when analyzing vasoconstriction.

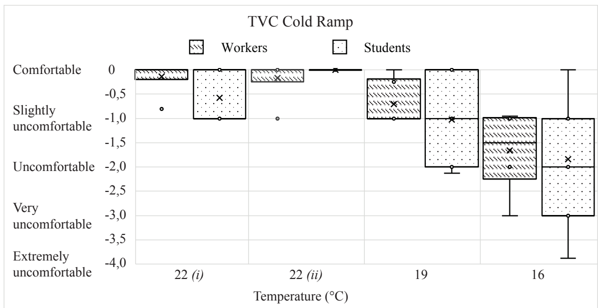

Fig. 4. Comparison of students' and workers' thermal comfort votes (TCV) during the cold ramp. On the horizontal axis, *22 (i)* refers to the participants' thermal comfort votes recorded as soon as they enter the thermal chamber; while *22 (ii)* refers to the ratings recorded after one hour.

Despite their lower $T_{sk\text{-}diff}$ values, students expressed slightly lower comfort ratings at 19°C and 16°C than their worker counterparts.

Results in Figures 5 and 6, referring to comparing students' and workers' TPV and TAV respectively, are coherent with the ones regarding TCV.

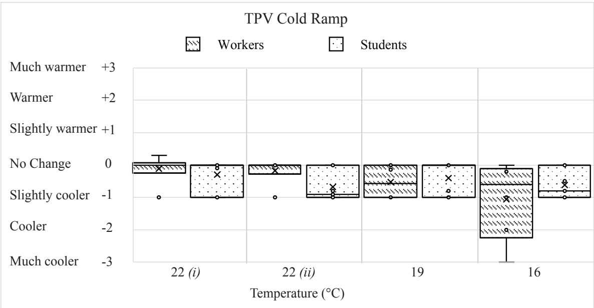

Fig. 5. Comparison of students' and workers' thermal preference votes (TPV) during the cold ramp. On the horizontal axis, *22 (i)* refers to the participants' thermal preference votes recorded as soon as they enter the thermal chamber; while *22 (ii)* refers to the ratings recorded after one hour.

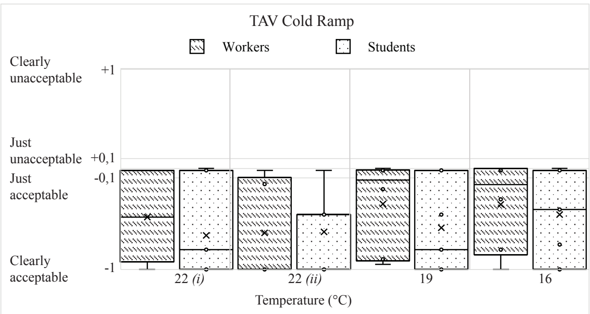

Fig. 6. Comparison of students' and workers' thermal acceptability votes (TAV) during the cold ramp. On the horizontal axis, *22 (i)* refers to the participants' thermal acceptability votes recorded as soon as they enter the thermal chamber; while *22 (ii)* refers to the ratings recorded after one hour.

In particular, the two subject samples expressed the same preferences (fig. 5) as the temperature decreased, but older workers also show a lower variability in the acceptability at the lowest temperatures (19-16°C) (fig. 6).

These results confirm the hypothesis that the thermoregulatory response decreases with consequent increases in vasoconstriction values and less awareness of thermal discomfort with advancing age.

3.2 Warm ramp

The trend in $T_{sk\text{-}diff}$ values of older workers (a) and students (b) during the warm ramp is represented in Fig 7. The figure shows that the trends in the two graphs are similar, except than the fact that the students show no signs of vasoconstriction by keeping the $T_{sk\text{-}diff}$ being close to zero for the whole length of the ramp (Figure 7b).

In contrast, the $T_{sk\text{-}diff}$ values of the older workers' graph (7a) vary between 0 and 4, with a peak just after entering the thermal chamber and one after one hour, just before the start of the hot ramp.

This second peak shows how maintaining a stationary posture slows down the metabolism with a consequent decrease in the temperature at the extremities.

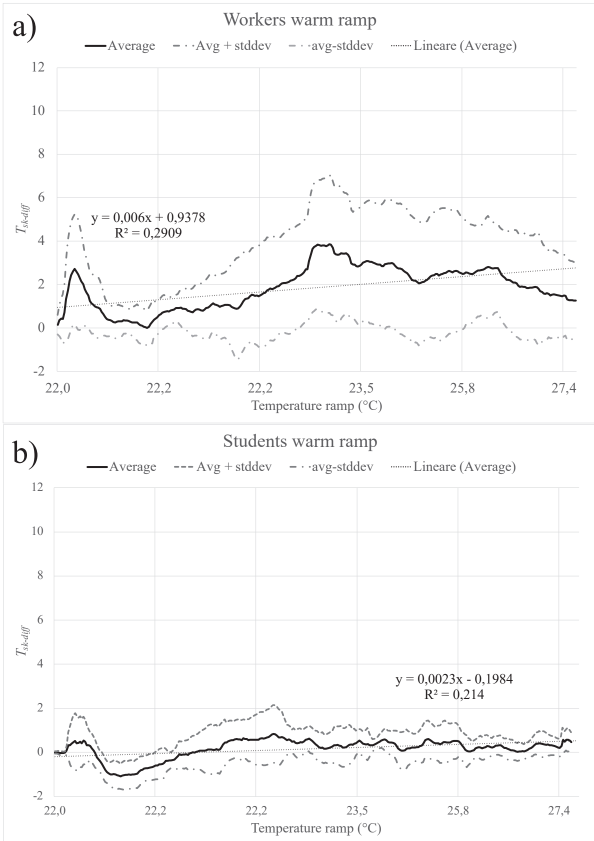

Fig. 7. Trend in $T_{sk\text{-}diff}$ value for older workers (a) and students (b) during the warm ramp.

Moreover, Figure 7a shows that a higher standard deviation in $T_{sk\text{-}diff}$ is present in the older workers' group: this sample is characterized by a greater subjectivity in the physiological response with respect to the students. Figure 8 shows the comparison between the TCV of students and that of workers.

Even though the average votes were similar, the older workers' votes at 25 °C and 28 °C show a higher variability during the hot ramp with respect to students, confirming the higher standard deviation analyzed in figure 7.

This is in contrast with what happened during the cold ramp, when a higher variability in the physiological response was not confirmed by the psychological (votes) given by workers.

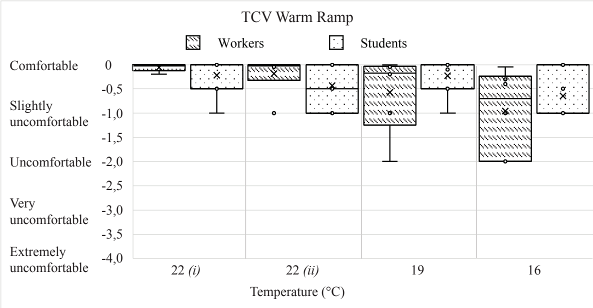

Fig. 8. Comparison of students' and workers' thermal comfort votes (TCV) during the warm ramp. On the horizontal axis, *22 (i)* refers to the participants' thermal comfort votes recorded as soon as they enter the thermal chamber; while *22 (ii)* refers to the ratings recorded after one hour.

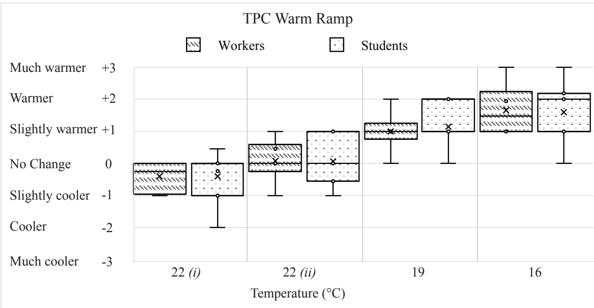

Fig. 9. Comparison of students' and workers' thermal preference votes (TPV) during the warm ramp. On the horizontal axis, *22 (i)* refers to the participants' thermal preference votes recorded as soon as they enter the thermal chamber; while *22 (ii)* refers to the ratings recorded after one hour.

Figure 9 shows a similar trend: the TPV expressed by the workers at 28°C confirms the higher subjectivity in the sample analyzed. Workers showed less tolerance to the hot ramp than their younger counterparts.

Despite the differences in TVC and TPC, the workers and students who took part in the experiment expressed similar thermal acceptability for the hot ramp, as illustrated in Figure 10.

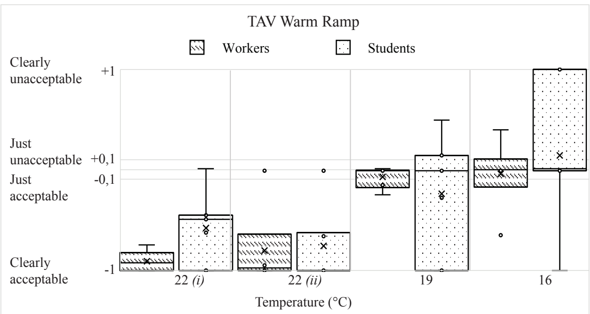

Fig. 10. Comparison of students' and workers' thermal acceptability votes (TAV) during the warm ramp. On the horizontal axis, *22 (i)* refers to the participants' thermal acceptability votes recorded as soon as they enter the thermal chamber; while *22 (ii)* refers to the ratings recorded after one hour.

Even in the case of the warm ramp, the results suggest that with advancing age, discomfort conditions provoke a more subjective and variable physiological response. In contrast with what happened during the cold ramp, this is also reflected in TCV and TPV, but not in TAV, responses collected by questionnaires.

4 Conclusions

The new composition of the workforce necessitates reformulating the conditions of the work environment to prevent discomfort conditions from impacting the health of older workers and vice versa.

Fanger's model assumes that older workers do not differ significantly from their younger counterparts. However, although everyone ages differently, a distinguishing feature of the age factor is the progressive decline in health that might result in reduced tolerance to environmental stresses and different thermal preference.

In this framework, this study aimed to assess subjects' thermal comfort, preference, and acceptability, as well as acclimatization capacity, comparing the physiological and psychological response of older workers (45-65 years old) and university students exposed to moderate temperature ramps.

Comparing the vasoconstriction graphs, older workers show higher values in both ramps. Greater vasoconstriction reveals a faster and more significant cooling of the extremities.

However, this result contrasts the comfort, preference, and thermal acceptability graphs related to the cold ramp, that show a higher tolerance of thermal discomfort conditions by older workers (higher thermal comfort votes). This result suggests that older workers might suffer more from thermal discomfort on the physical point of view but being less aware of it.

This result is partially in contrast with what happened during the hot ramp: even though the psychological responses of the two groups were similar in their average, older workers showed a higher variability in terms of thermal comfort and thermal preference.

In contrast with what is suggested by the PMV-PPD model, our results suggest that elderly workers might have similar neutral temperatures with respect to young people, but under some discomfort conditions different percentages of dissatisfied might be present. Our experiment highlights that percentages of dissatisfied might be higher during the exposure to a warm ramp.

This experimental study is based on a minimal data sample and is only intended as a first age-based comparison analysis to preliminary study the validity of current thermal comfort model for older workers. Soon, we aim to investigate further the results obtained, by extending the study to gather more data on older workers' acclimatization capacity and thermal preferences.

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Furthermore, the experiment should be repeated with female subjects to be able to generalize the results to the whole population, and/or highlight potential differences between genders in the temperature perception when ageing.

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