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Farah Z. Al-Atrash, Runa T. Hellwig, Andreas Wagner

Indoor environment in office buildings – Perception of personal control und use of adaptive opportunities at workplaces

Personal control has a considerable impact on individual perception of the indoor climate. This paper's objective is to shed more light on the perception of control at office workplaces by analysing: 1) the impact of perceived control on perception of indoor climate, 2) the effect of office type and season on level of control perceived, 3) objectively available adaptive opportunities; 4) subjective perception of their availability; 5) occupants' desire for certain adaptive opportunities; 6) how often and which controls were exercised; and 7) reasons for not exercising available adaptive opportunities. New variables were introduced: i) consistency of perception of controls and ii) conformity to expectation of controls, and their correlation with the level of personal control perceived hypothesised. A longitudinal survey was carried out in three office buildings (two mixed-mode, one free-running) in the hot-summer Mediterranean climate of Amman, Jordan during four seasons. Indoor climate perception correlates positively with perceived control. Office type affects level of perceived control but not season. Most frequent stated reason for not exercising available adaptive opportunities was 'no need to change'. In this study, perceived control is not correlated with consistency of perception of controls but correlated with conformity to expectation of controls.

Keyword occupant expectation; occupant behaviour; office building; personal control; affordance

Raumklima in Bürogebäuden – Wahrnehmung der individuellen Kontrolle und Nutzung von Anpassungsmöglichkeiten am Arbeitsplatz

Die individuelle Kontroll- und Anpassungsmöglichkeit des Raumklimas hat einen erheblichen Einfluss auf die individuelle Wahrnehmung des Raumklimas. Ziel dieses Beitrages ist es, die wahrgenommene Kontrolle an Büroarbeitsplätzen durch eine Analyse der folgenden Faktoren näher zu beleuchten: 1) Auswirkung der wahrgenommenen Kontrolle auf die Wahrnehmung des Innenraumklimas, 2) Auswirkung des Bürotyps und der Jahreszeit auf den Grad der wahrgenommenen Kontrolle, 3) objektiv verfügbare Kontroll- und Anpassungsmöglichkeiten, 4) subjektive Wahrnehmung deren Verfügbarkeit, 5) Nutzerwunsch nach bestimmten Kontroll- und Anpassungsmöglichkeiten, 6) welche Kontroll- und Anpassungsmöglichkeiten wurden wie oft benutzt, und 7) Gründe für die Nichtbenutzung verfügbarer Kontroll- und Anpassungsmöglichkeiten. Für die Analyse wurden die neuen Variablen i) Konsistenz der Wahrnehmung von Kontroll- und Anpassungsmöglichkeiten und ii) Konformität mit den Erwartungen an Kontroll- und Anpassungsmöglichkeiten eingeführt sowie deren Korrelation mit dem Grad der wahrgenommenen individuellen Kontrollen angenommen. In drei Bürogebäuden (davon zwei mit öffenbaren Fenstern und maschineller Lüftung und dezentraler Kühlung/Beheizung und eines weder gekühlt noch beheizt) wurde in Amman's (Jordanien) Mittelmeerklima mit heißen Sommern während vier Jahreszeiten eine Längsschnittstudie durchgeführt. Die Wahrnehmung des Raumklimas korreliert positiv mit der wahrgenommenen Kontrolle. Der Bürotyp beeinflusst das Niveau der wahrgenommenen Kontrolle, die Jahreszeit nicht. Der am häufigsten angegebene Grund für die Nichtbenutzung verfügbarer Kontroll- und Anpassungsmöglichkeiten war „keine Notwendigkeit zur Veränderung". In dieser Studie korreliert die wahrgenommene Kontrolle nicht mit der Konsistenz der Wahrnehmung von Kontroll- und Anpassungsmöglichkeiten, jedoch mit der Konformität der Erwartung an Kontroll- und Anpassungsmöglichkeiten.

Stichworte Bürogebäude; Nutzererwartung; Nutzerverhalten; wahrgenommene Kontrolle; Affordance

1 Introduction

Personal control over indoor climatic conditions, i.e. having the opportunity to adjust the conditions to actual subjective needs, is a key factor in comprehensive models of indoor climate perception as e.g. the adaptive thermal comfort model (Nicol and Humphreys, 1973 [1]; Auliciems, 1981 [2]; de Dear, Brager and Cooper, 1997 [3]). Though personal control is incompletely represented by clothing insulation in the heat balance model, Fanger, 2001 [4] pointed out the importance of personal control as one of the main factors for thermal satisfaction: *"Of course 100 % satisfaction with indoor climate can be achieved, it just means that you have to offer effective personal control right there where people are"*.

Having the opportunity of personal control enables two of the three adaptive principles [3] of the adaptive thermal comfort model: behavioural adaptation by control action (Brager and de Dear 1998 [5]) and psychological adaptation through the existence of a mind-relaxing confidence about opportunities for behavioural actions in order to adjust the indoor climatic conditions in case of discomfort (Aronoff and Kaplan 1995 [6], Hellwig 2015[7]). Therefore, personal control has a considerable positive impact on individual perception of and satisfaction with the indoor environment ([7]; Leaman and Bordass, 1999 [8]; Hellwig, 2005 [9]; Hellwig und Bischof, 2006 [10]; Gossauer, Leonhart and Wagner, 2006 [11]; Ackerly et al., 2011 [12]; Boerstra et al., 2013 [13], [14]; Boerstra, 2016 [15]) and its absence goes along with higher prevalence of sick building syndrome symptoms (e.g. Bischof et al., 2003 [16]; Marmot et al., 2006 [17]). Leaman and Bordass [8] identified five major impact variables on productivity in buildings. Personal control is the first variable on this list, meaning the higher the level of personal control perceived by the occupants, the more tolerant and productive they are.

Currently, building designers and operators doubt the benefits of personal control over indoor climate because of assumed negative effects on energy use and often choose to avoid operable windows, adjustable thermostats and other control opportunities (van Hoof, Mazej, Hensen, 2010 [18]; Fabi, Spigliantini and Corgnati, 2017 [19]; Hellwig, Schweiker, Boerstra, 2020 [20]; Usable buildings, 2021 [21]). Possible reasons could be the lack of knowledge about the comfort, health and productivity benefits of personal control opportunities or that insufficient weight is put on their design the building design process [18]. The understanding of how to integrate the adaptive concept, i.e. adaptive control opportunities into a responsive design concepts remains limited (Hellwig et al., 2019 [22]). As a result, buildings are becoming more centrally controlled instead of occupant controlled; in particular, those sealed buildings, which depend on centrally operated HVAC systems.

Paciuk, 1990 [23] distinguishes three levels of personal control: available, exercised, and perceived control. 1 – Available control refers to the type of control opportunities available to the occupants, such as operable windows, interior/ exterior doors, blinds, personal fans, personal heaters and thermostats. It could also include the dress code and further factors influencing the interaction between the occupant and the building. 2 – Exercised control refers to the relative frequency with which the building occupants exercise indoor environmental adaptive control behaviours by adjusting the available control opportunities. 3 – Perceived control refers to the degree to which building occupants believe they can cause desired changes in the indoor environment. Hellwig defines in [7] personal control as occupants having the opportunity to adjust their indoor environment according to their needs and preferences, in the case of discomfort driven by what the built and social environment offer or allow for (called affordances or adaptive opportunities), the occupants' personality and their knowledge and competences on how to cause changes of the indoor environment surrounding them, both based on their previous experience and actual internal state.

However, too little is known about which of the aspects of personal control, e.g. available adaptive control opportunities, reasons for not exercising adaptive control behaviours, influence of office type or season, occupants' expectations as well as the psychological issue of both the belief of having access to the adaptive control opportunities and the effectiveness of having this access, are most important to determine the degree of personal control (e.g. Fountain, Brager and de Dear, 1996 [24]; Brager and de Dear, 2003 [25]; Gossauer and Wagner, 2007 [26]; [13]; [14]; Langevin, 2014 [27]; [7], [15]. According to [8]; [14]; Schweiker and Wagner, 2016 [28], the level of perceived control over temperature and ventilation decreases with the increase in the number of occupants sharing a workspace.

Though [23] found that the number of *available* control options affected thermal comfort and satisfaction positively, when occupants were relatively often engaged in making adjustments to the available control options (*exercised* control), they were slightly less comfortable and less satisfied with their thermal environment.

In this study, we focus on the indoor environmental control opportunities, called adaptive opportunities (Baker and Standeven, 1997 [29]), of the building and how they are used by the occupants. Clothing behaviour as an important adaptive opportunity on person level is not within the scope of this paper and was analysed elsewhere (Al-Atrash, Hellwig and Wagner, 2020 [30]). A conceptual framework of the interrelation between objectively available, perceived available and desired controls will be introduced and analysed. The hypothesis is, that deviations of the occupants' perception from either reality (knowledge about or restriction of objectively available controls) or desired controls (expectation) affect the level of perceived control (Fig. 1). Through a detailed longitudinal approach, the impact of objectively available controls, perceived availability of controls and desired controls is investigated. Furthermore, exercised control and the reasons for not exercising available adaptive opportunities as well as the effect of office type and season on perceived control is analysed.

2 Material and methods

Data were collected in three office buildings (Fig. 2) during four seasons: spring, summer, autumn 2016 and winter 2017. The buildings are located in Amman, which has a hot-summer Mediterranean climate (Csa) according to Köppen-Geiger climate classification (Rubel et al., 2017 [31]). Two of these buildings, building 1 and building 2, are mixed mode buildings, i.e. of concurrent type (Brager

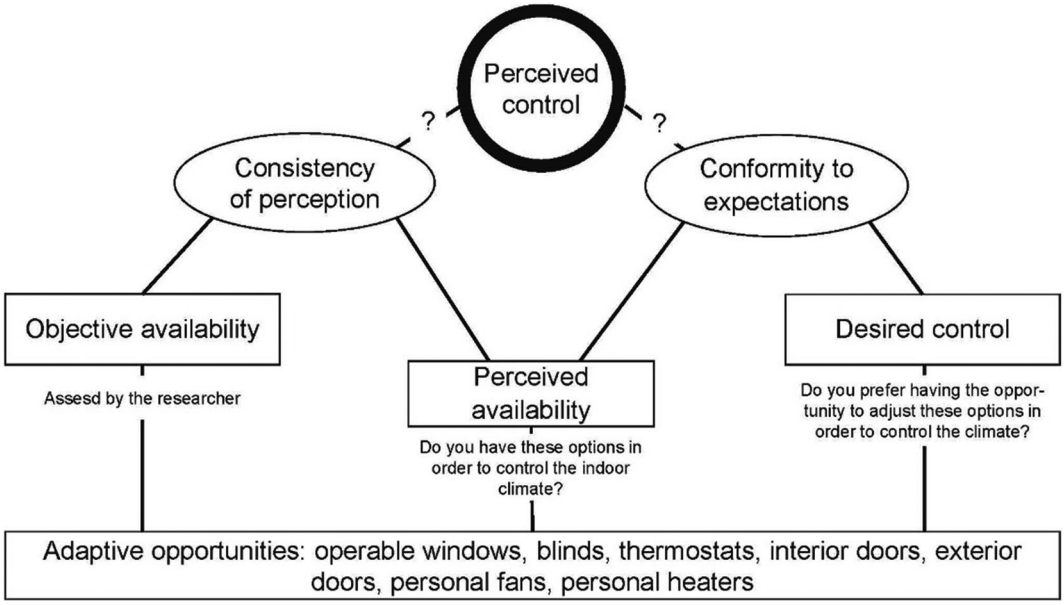


Fig. 1 Conceptual framework for analysis of the impact of knowledge (consistency of perception) and conformity to expectation on perceived control in this study.
Konzeptionelle Modell für die Analyse des Einflusses von Wissen (Konsistenz der Wahrnehmung) und Erwartungskonformität auf die wahrgenommene Kontrolle in dieser Studie.

2006 [32]), and were awarded LEED GOLD certificates. Both mixed mode buildings are mechanically ventilated buildings with decentralized room wise split units for heating and cooling allowing the temperature to be adjusted by the occupants in each office. The third building represents a free-running traditional building. The built-up areas are 25,600 m^2, 4095 m^2 and 300 m^2 for buildings 1, 2 and 3 respectively. The building have three different office types: single offices, shared offices and open-plan offices (Fig. 3). Table 1 provides an overview on the main indoor and outdoor environment parameters. In total, a sample of 119 occupants was willing to participate in the longitudinal survey. The number of occupants differs slightly between the different seasons. The mean clothing level is around 0.6 clo in spring, summer and autumn, except in building 1 and between 1.0 and 1.2 clo in winter (Table 1). Detailed data on the outdoor and indoor environment conditions, clothing level, measurements as well as the more details about the field surveys are described in [30].

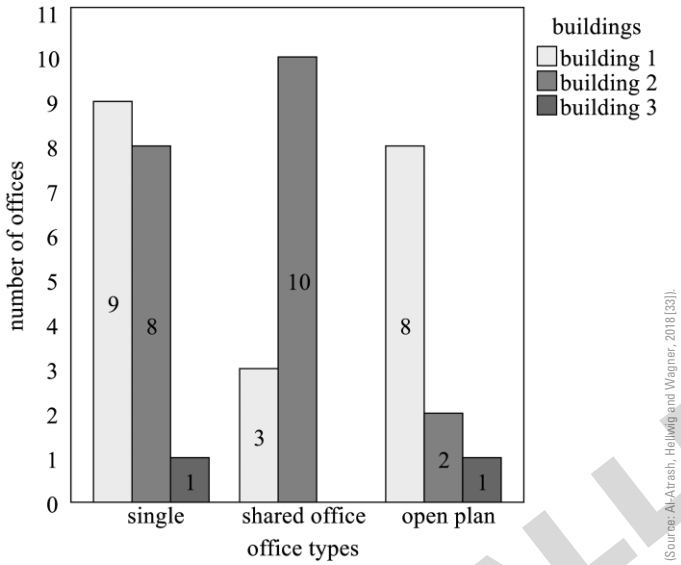
Data were gathered according to the following procedure: Firstly, the researcher objectively assessed available control opportunities in the offices. Exercised control was documented while occupants were completing the set of questions. Secondly, building occupants completed a set of questions about available, desired and their level of perceived control, as well as exercised control and the reasons why not having exercised the available adaptive controls, thermal perception and air quality perception. Table 2 shows the set of questions related to this paper. The questions were available in both Arabic and English languages. The occupants answered the set of questions twice a week for a period of two to three weeks per season. The mode of responses for each person per each question has been calculated for each season for the no-

Tab. 1 Overview on participants and median values of main indoor and outdoor climate parameters measured during the study.
Überblick über die Teilnehmer und die wichtigsten Medianwerte der während der Studie gemessenen Innen- und Außenklimaparameter.

Parameter	season/ building											
	spring			summer			autumn			winter		
	b1	b2	b3	b1	b2	b3	b1	b2	b3	b1	b2	b3
Participants	37	23	7	39	29	6	31	21	5	28	28	6
T_{mm}, °C	19.0	21.0	20.0	27.0	27.0	28.0	22.0	24.0	23.0	6.0	6.0	7.5
T_{op}, °C	23.68	24.08	24.6	23.0	23.5	26.2	23.3	24.2	25.5	23.4	23.5	17.6
RH, %	38	38	27	51	46	55	45	37	35	36	37	55
CO_2	644	523	451	683	522	458	735	546	511	809	734	1800
I_{cl}	1.0	0.6	0.6	0.6	0.6	0.6	0.6	0.6	0.7	1.0	1.1	1.2

T_{mm}: monthly mean outdor temperature; T_{op}: indoor operative temperature in °C (calculated); RH: relative humidity in %; CO_2 concentration in ppm; I_{cl} total clothing insulation (excluding chair) in clo. b1: building 1, b2: building 2, b3: building 3

Fig. 2 Interior view of offices in building 1, building 2 and building 3 respectively (from left).
Innenansicht von Büros in Gebäude 1, Gebäude 2 und Gebäude 3 (von links).



(Source: Al-Atrash, Hellwig and Wagner, 2018 [33]).

Fig. 3 Prevalence of office types within the three buildings
Anzahl der Bürotypen in den drei Gebäuden.

minal scales, while the median was calculated for ordinal scales.

Spearman's rank correlation (two-tailed, $\alpha = 0.05$) was used to analyse correlations between variables on the ordinal scale level. Kruskal–Wallis test ($\alpha = 0.05$) was applied to identify differences in the median of perceived control between more than two different independent groups. Friedmann test ($\alpha = 0.05$) was applied for testing the difference between several dependent groups. Dunn-Bonferroni pairwise post-hoc tests were applied for contrasts between groups. In order to test the impact of the variables objective availability of controls, perceived availability of controls and desired controls on the level of perceived control, two new variables were introduced: 1) the consistency between objective availability and perceived availability of controls (knowledge about controls, constraints) and 2) the conformity to expectations, which describes the congruency between desired and perceived availability of controls. Fig. 1 shows a simplified conceptual framework of the main analysis in this study.

3 Results

3.1 Thermal comfort and IAQ perception, perceived control and impact of contextual factors

Concerning the thermal comfort perception, 92 % of the occupants were comfortable (scale points 3 to 5) and only 8 % voted for uncomfortable or very uncomfortable. Occupants also perceived good air quality (92 %) (scale points 3 to 5) while only 8 % voted for bad or very bad air quality.

Overall scores for perceived control did not differ significantly with season. The median of perceived control was 3 for spring and 4 for summer, autumn and winter (Fig. 4). Office type had a significant impact on perceived control, visible in each season (Fig. 5). The median value of perceived control for single office type is the highest in all seasons. Significant differences appeared between single and open-plan offices in all seasons, and between single and shared offices in winter.

Perceived control was found to correlate positively with thermal comfort perception and air quality perception in all seasons (Table 3), suggesting that individuals, who perceive control, are more thermally comfortable and are more positive towards air quality. A significant difference in the median of perceived control of about one unit on the five-point scale for those who voted 'not comfortable' (median = 3) and those voted 'comfortable' (median = 4) was identified in buildings 1 and 3. Statistical analysis reveals significant differences for all buildings (Table 4).

3.2 Objective availability

The analysis of objectively available controls has been related to the office type. Only offices occupied by participants in the survey were considered. Both, building 1 and 2 contain three office types: single offices, shared offices inhabited by two to five persons in building 2 and two to three persons in building 1. The third type is an open plan office shared by up to ten persons. Building 3 has one

Tab. 2 Questions of the questionnaire used relevant to this paper. For more details on thermal comfort in the investigated buildings, see [30] and [34].
Für die vorliegende Analyse relevante Fragen des Fragebogens. Für weitere Einzelheiten zur thermischen Behaglichkeit in den untersuchten Gebäuden, siehe [30] und [34].

Question	Response categories
Thermal comfort perception How do you rate the temperature at this moment in your office?	very uncomfortable (1) … very comfortable (5). five-point ordinal scale
Air quality perception How do you perceive the air quality at this moment in your office?	very bad (1) … very good (5) five-point ordinal scale
Perceived control How much control do you have to change 'the thermal conditions' of your office (at the moment)?	no control at all (1) … a lot of control (5) five-point ordinal scale
Perceived availability Do you have these options in order to control the indoor climate? Operable window, door to interior space, door to exterior space, blinds, personal fan, personal heater and thermostat.	– yes – no
Desired control Do you prefer having the opportunity to adjust these options in order to control the indoor climate? (at the moment)? Operable window, door to interior space, door to exterior space, blinds, personal fan, personal heater and thermostat.	– yes – no
Exercised control What type of adjustment did you make to the given 'options to control indoor climate' during the last hours? Operable window, door to interior space, door to exterior space, blinds, personal fan, personal heater and thermostat.	– opened without asking others – opened after asking others – closed without asking others – closed after asking others – no adjustment – not applicable
Reasons for not exercising available controls What were the reasons you did not take the given 'options to control indoor climate'?[1)] Operable window, door to interior space, door to exterior space, blinds, personal fan, personal heater and thermostat.	– Would not have helped – Cannot adjust option any further – Was not agreeable to others in the space – Not sure if it would be OK with management – Not worth asking others' permission – Not worth disturb my work – No need-co-worker did this – Wanted to exhaust other control options first – I was comfortable enough

1) Categories after [27].

single office and one open plan office shared by around six persons (Fig. 3).

Appendix I shows the available controls in the offices of the three buildings. *Building 1* has nine single offices with operable windows, interior doors, blinds and adjustable thermostats. The only available controls in the three shared offices are interior doors and adjustable thermostats. These offices were occupied by six participating persons. Occupants in these offices have to rely on mechanical ventilation. In all eight open plan offices, adjustable thermostats for the split units are available, while two out of eight open plan offices lack operable windows and blinds. 46 persons occupied the open plan offices.

Building 2 has eight single offices with interior doors and adjustable thermostats. One office lacks operable windows; two offices do not have blinds. The single offices were occupied by nine different persons (instead of eight) because the occupancy of one office changed during the longitudinal survey. All ten shared offices have interior doors and thermostats. Three of these offices lack operable windows as well as blinds. A personal fan was found in one of these offices. Personal heaters were not available. There were 32 people in these offices. The two open plan offices have operable windows, interior and exterior doors in addition to thermostats. They lack blinds, personal fans and heaters. The open plan offices were shared by nine persons.

The single office in *building 3* has operable windows, an exterior door, blinds, a personal fan and a personal heater. The open plan office, which was shared by six persons, has operable windows, an interior door, blinds and personal heaters.

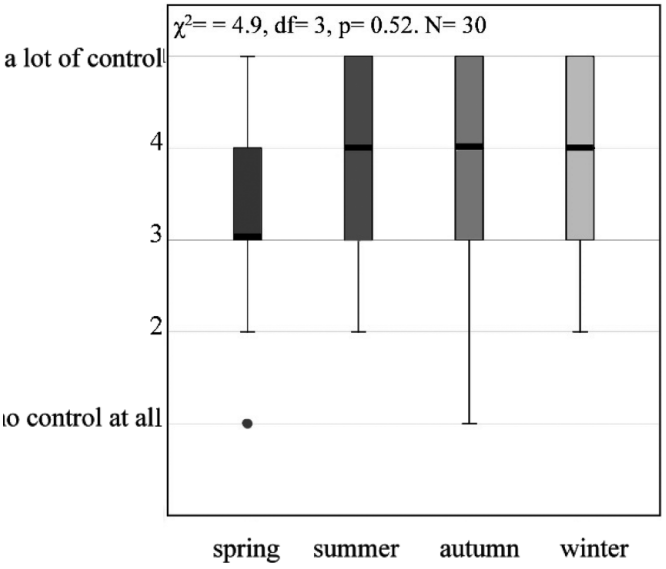


Fig. 4 Perceived control versus season. Analysis based on Friedman test, occupants who responded in all seasons: $n = 30$.
Wahrgenommene Kontrolle je nach Jahreszeit; Analyse auf Basis des Friedman-Tests; Nutzer, die in allen Jahreszeiten geantwortet haben: $n = 30$.

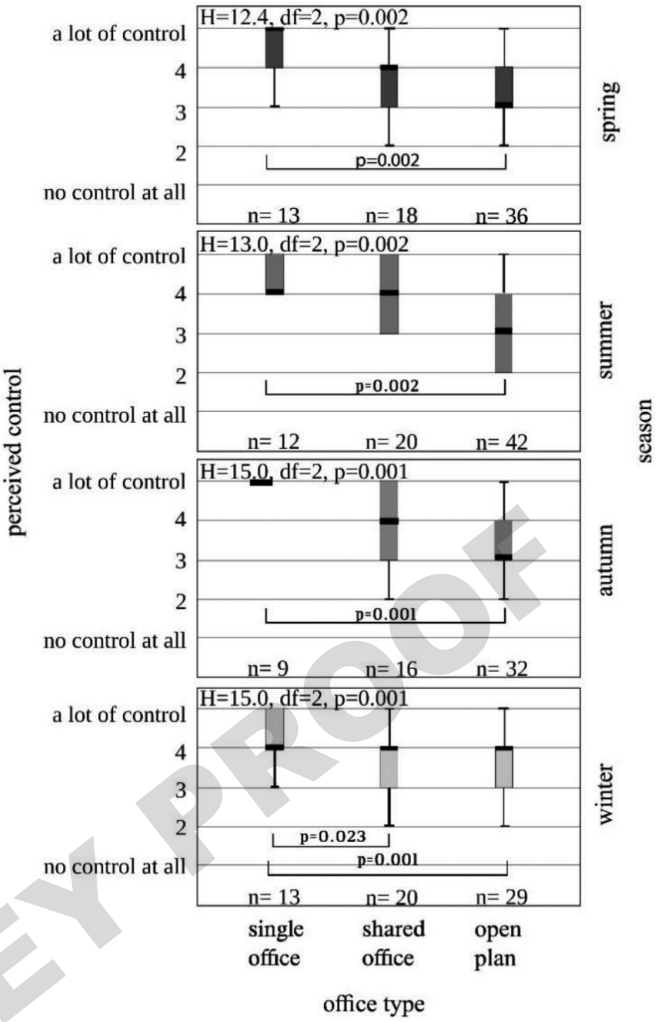


Fig. 5 Perceived control versus office type in all seasons; (Kruskal-Wallis test, Dunn Bonferroni pairwise post-hoc test for office type, significant results are indicated with their p-value; numbers n refer to the number of occupants.
Wahrgenommene Kontrolle im Vergleich der Bürotypen in allen Jahreszeiten; Kruskal-Wallis-Test, paarweiser Dunn-Bonferroni-Post-hoc-Test für die Bürotypen; signifikante Ergebnisse sind mit zugehörigem Signifikanzwert p gekennzeichnet); die Zahlen n beziehen sich auf die Anzahl der Nutzer.

3.3 Perceived availability

Perceived availability in this study is defined as the subjective perception of availability of certain controls. It relates to the subjective opinion or belief of having or not having adaptive control options available. Appendix I shows the perceived availability of different controls by each person in the buildings. In *building 1*, all nine occupants of the single offices believed that they had access to operable windows, interior doors, blinds and adjustable thermostats. Three occupants reported perceived availability to control exterior doors. All six occupants of the shared offices stated that they could control interior doors and adjustable thermostats. Two of them declared the absence of operable windows and blinds. The occupants of the open plan offices reported differing perceptions on availability of operable windows, interior doors, blinds and adjustable thermostats.

In *building 2*, almost all occupants in all three office types reported having control over windows and interior doors. Occupants in open plan offices perceived the availability to control exterior doors. However, approximately half of the occupants of other office types perceived this control as available. Thermostats were perceived to be available by all the respondents except for one in the shared offices.

In *building 3*, all occupants in single and open plan offices stated they already had control over operable windows and blinds. Concerning the personal fan control option, one person in the single office answered yes, but no one had such control in the open plan office. The availability of controls reported by the occupants was not fully congruent with the documentation of the researcher.

3.4 Desired controls

This study defines desired controls as the occupant's wish for control options to adjust the indoor climate. The question referred to in this part is: Do you prefer having the opportunity to adjust these options in order to control the indoor climate?

Appendix I shows the responses regarding desired controls in the buildings. In *building 1*, none of the occupants in shared offices wished to have control over personal fans and heaters, whereas some of the single and open plan occupants did. Operable windows and adjustable thermostats were the most desired control options in all office types. The wish to have personal fans and heaters also appeared in this type of office.

In *building 2*, most of the occupants in both single and shared offices wished to have control over operable win-

Tab. 3 Spearman rank-order correlation between perceived control and both, thermal comfort and air quality perception, in all seasons (based on the vote's mode or median per occupant), per each season (based on all votes conducted including multiple per occupant). Significant results are in bold. ($\alpha = 0.05$, two-tailed) [33].
Spearman-Rangkorrelationskoeffizienten von wahrgenommener Kontrolle und thermischer Behaglichkeit bzw. Luftqualitätswahrnehmung über alle Jahreszeiten (basierend auf dem Modus oder Median der Antworten jedes Nutzers), pro Jahreszeit (basierend auf allen Nutzerantworten, einschließlich mehrerer Antworten pro Nutzer). Signifikante Ergebnisse sind fett gedruckt. ($\alpha = 0{,}05$, zweiseitig) [33].

	perceived control versus		N
	thermal comfort perception	air quality perception	
	r_s	r_s	
all seasons	**0.45**	**0.51**	119
spring	**0.34**	**0.32**	67
summer	**0.52**	**0.41**	74
autumn	**0.49**	**0.29**	57
winter	**0.42**	**0.41**	62

dows, interior doors, blinds and adjustable thermostats. Some of them wished to have control over personal fans and heaters. Interior doors and thermostats were the most desired control options in the open plan offices.

In *building 3*, in the single office, the most desired control options were an interior door, an exterior door, blinds, an adjustable thermostat, personal fan and personal heater, followed by operable windows, while the most desired control option at the open plan office was adjustable thermostat.

3.5 Consistency of perceived availability and objective availability

Does individual perception of controls available reflect objectively available controls at individual workplaces? Therefore, objective availability (binary variable) was subtracted from perceived availability (binary variable) for providing information on consistency, having three categories: i) '0': occupants' perception is *consistent* with the real conditions, ii) '-1': occupants may perceive some *restrictions* in accessing the respective control option, iii) '+1' occupants assume this control option is available, although it is not objectively available (*false positive assumption*). In the latter case, the occupants have never even tried to change the thermal environment with this control option or this control option is not important from their point of view.

Fig. 6 shows the prevalence of categories of consistency between perceived availability and objective availability in the three buildings. In the case of the single offices, two persons believed they had access to outdoor space in building 1, while four persons believed this in building 2. The perceived availability of the other control options was consistent with the objective availability in building 1. One person believed there was access to blinds in building 2. There was the perception that access to interior doors and blinds was restricted in building 2. The perceived availability of controls in shared offices in building 1 was consistent with the objective availability for adjustable thermostats and interior doors, but not for operable windows and blinds, which two persons believed they had access to, nor for an exterior door, which one person believed there was access to. In building 2, perceived availability was in accordance with the objective availability only for interior doors. There was the perception of restricted access to exterior doors, blinds and the thermostat. In building 1, the perception of restrictions for all control options appeared in the open-plan office type, with the smallest proportion for access to exterior doors and the largest share for interior doors. In the case of building 2, restrictions were perceived in the open plan office type just as in the case of operable windows. In building 3, the perceived availability of most of the control options was in accordance with the objective availability. Restrictions were perceived for personal fans and personal heaters in the single office and for personal heaters in the open plan office.

Fig. 7 displays for each category of consistency between perceived availability and objective availability, the distribution of the occupants' votes on perceived control for each main adaptive opportunity and season. Personal

Tab. 4 Distribution of the occupants' votes on perceived control for both 'not comfortable' and 'comfortable' categories. 1: no control at all, 5: a lot of control. Mann-Whitney-U-test ($\alpha = 0.05$), the significance level is 0.05 (two-tailed). Numbersin the cells refer to the number of responses.
Verteilung der Nutzerantworten zu wahrgenommener Kontrolle in den Kategorien „nicht behaglich" und „behaglich"; 1: überhaupt keine Kontrolle, 5: sehr viel Kontrolle. Mann-Whitney-U-Test ($\alpha = 0{,}05$), Signifikanzniveau 0,05 (zweiseitig). Die Zahlenangaben beziehen sich auf die Anzahl der Antworten.

	building 1		building 2		building 3	
	comfortable	not comfortable	comfortable	not comfortable	comfortable	not comfortable
Number	260	71	199	18	87	24
75th percentile	5	4	5	4	4	4
Median	4	3	4	4	4	3
25th percentile	3	2	3	3	3	2
Mann-Whitney-U-test	$H = 9.1$, $df = 1$, $\boldsymbol{p = 0.003}$		$H = 5.2$, $df = 1$, $\boldsymbol{p = 0.022}$		$H = 11.6$, $df = 1$, $\boldsymbol{p = 0.001}$	

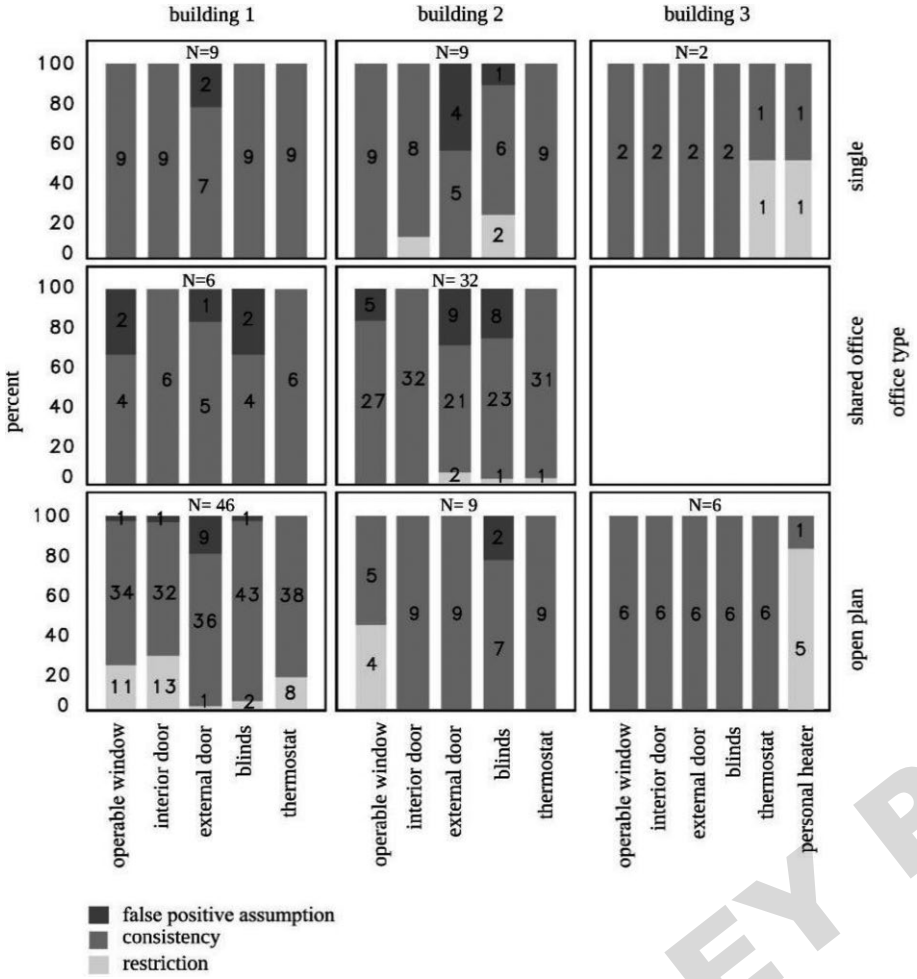


Fig. 6 Categories of consistency between perceived availability and objective availability of controls in the three buildings. Numbers in the columns represent the respective absolute number of occupants.
Kategorien der Konsistenz (Übereinstimmung) zwischen wahrgenommener Verfügbarkeit und objektiver Verfügbarkeit der Kontroll- und Anpassungsmöglichkeiten in den drei Gebäuden. Die Zahlen in den Säulen geben die jeweilige absolute Anzahl der Nutzer an.

fans and heaters were excluded from this analysis, as they were rarely available. The analysis shows no significant differences in the three categories' median of perceived control ($p > 0.05$) of the different adaptive opportunities during the different seasons, except the analysis related to interior door adaptive opportunity in spring ($p = 0.04$). For operable windows, blinds, interior doors and thermostats, the median perceived control scores for the categories 'consistency' and 'false positive assumption' lie, in most cases, one unit above the median score for the category 'restriction'.

3.6 Conformity to expectation

The same procedure as in the previous section was applied to the binary variables perceived availability and desired controls, resulting in information on conformity to occupants' expectation: i) '0': perceived availability matches occupants' expectation, is *conform to expectation*, ii) '–1': perception of a lack of control, hence a *negative non-conformity* to expectation, and iii) '+1' more control options are perceived to be available than the occupant desired (*positive non-conformity to expectation*).

Fig. 8. shows the frequency of the categories of conformity between perceived availability and desired controls in the three buildings. *Building 1:* In the case of single offices, the perceived availability of operable windows, interior doors, blinds and adjustable thermostats is in conformity with the desired controls or shows positive non-conformity. Four persons desired exterior doors but did not perceive their availability. Some occupants in shared offices lacked the opportunity to control operable windows, exterior doors and blinds while few occupants in open-plan offices missed the opportunity to control operable windows, interior and exterior doors blinds, and thermostats. *Building 2:* In single offices, the results were similar to those in building 1, but the category negative non-conformity also appeared for operable windows and blinds. Occupants in shared offices lacked the opportunity to control operable windows, exterior doors and blinds, while in open plan offices, occupants only lacked the operable windows and blinds control options. Occupants in *building 3* lacked the opportunity to control interior doors, in the case of the single office, and the exterior door in the open plan office, as well as personal fans and personal heaters in both offices.

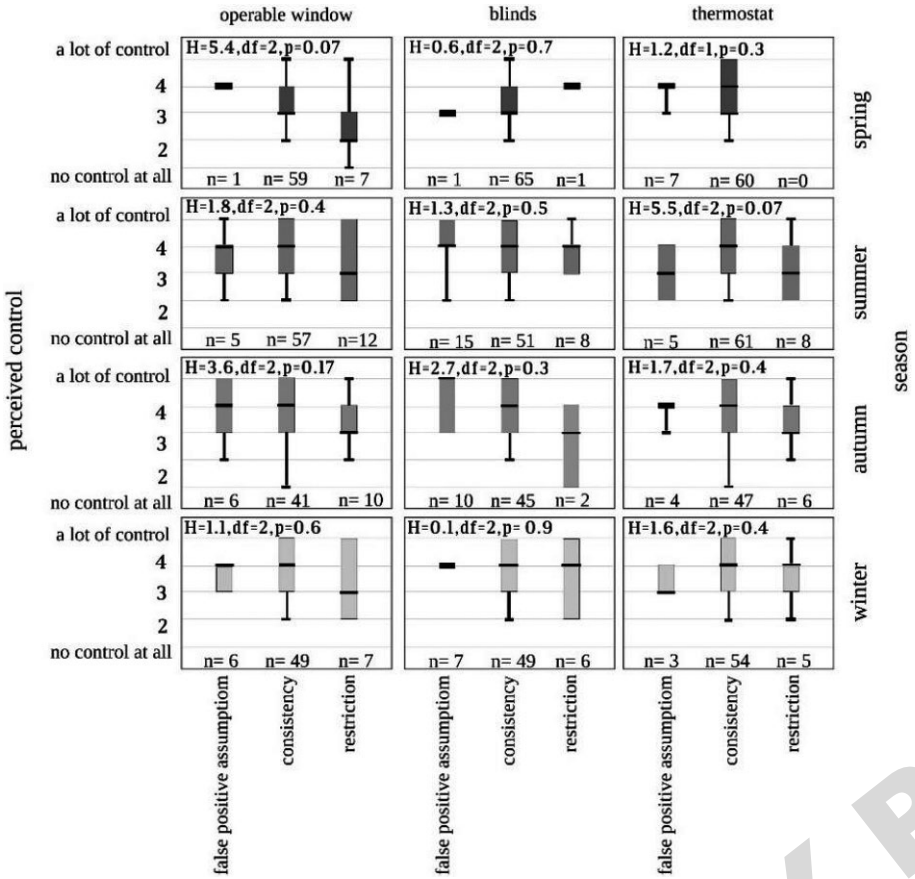


Fig. 7 Perceived control for the three categories of consistency between perceived and objective availability. Analysis based on Kruskal-Wallis test ($\alpha = 0.05$). Numbers n refer to the number of occupants.
Wahrgenommene Kontrolle für die drei Kategorien der Konsistenz (Übereinstimmung) zwischen wahrgenommener und objektiver Verfügbarkeit. Die Analyse basiert auf dem Kruskal-Wallis-Test ($\alpha = 0{,}05$). Die Zahlen n beziehen sich auf die Anzahl der Nutzer.

Fig. 9 displays for each category of conformity the distribution of the occupants' votes on perceived control for each main adaptive opportunity and season. Again, personal fans and heaters were excluded from this analysis. The analysis shows significant differences in the three categories' median of perceived control ($p < 0.05$) of operable windows in spring and summer, and also blinds in spring. The analysis regarding the other adaptive opportunities shows no significant differences in the three categories' median of perceived control ($p > 0.05$). For all adaptive opportunities, the median of perceived control score for the category '*negative non-conformity*' lies in most cases one unit lower than the median scores for the categories '*conformity*' and '*positive non-conformity*'. For significant cases, contrasts were tested (Fig. 9).

3.7 Exercised control and reasons for not exercising control

Exercised control was investigated as a function of the office type in all four seasons. Exercised control (categories see Table 2) was calculated by percentage and with reference to the number of occupants who perceived available control. In *spring*, the frequencies of responses in single offices are distributed equally between 'opened without asking others' and 'no adjustment' (44 %). In both, the shared offices and the open plan offices the highest prevalence is in 'no adjustment' (62 %). The other responses are distributed evenly between the other categories of exercised control. In single offices, the highest prevalence found was 'no adjustment', followed by 'opened without asking others' and 'closed without asking others'. In shared offices and open plan offices, 'no adjustment' shows the highest frequency, followed either by opening the control options 'after asking others' or 'without asking others'. The lowest prevalence relates to closing the control options 'after asking others' or 'without asking others'. A similar trend as for spring was found among summer, autumn and winter.

The results showed that the highest response rate to the question on exercised control was 'no adjustment', in all seasons. The most prevalent reason for not using indoor climate controls was: 'I was comfortable', with 56 % in single offices, 44 % and 47 % in shared and open-plan offices respectively. All possible reasons for not exercising available adaptive controls were divided into three main categories:

i) '*no success expected*': integrates the reasons 'would not have helped', 'cannot adjust option any further', 'was not agreeable to others in the space', and 'not sure if it would be ok with management';

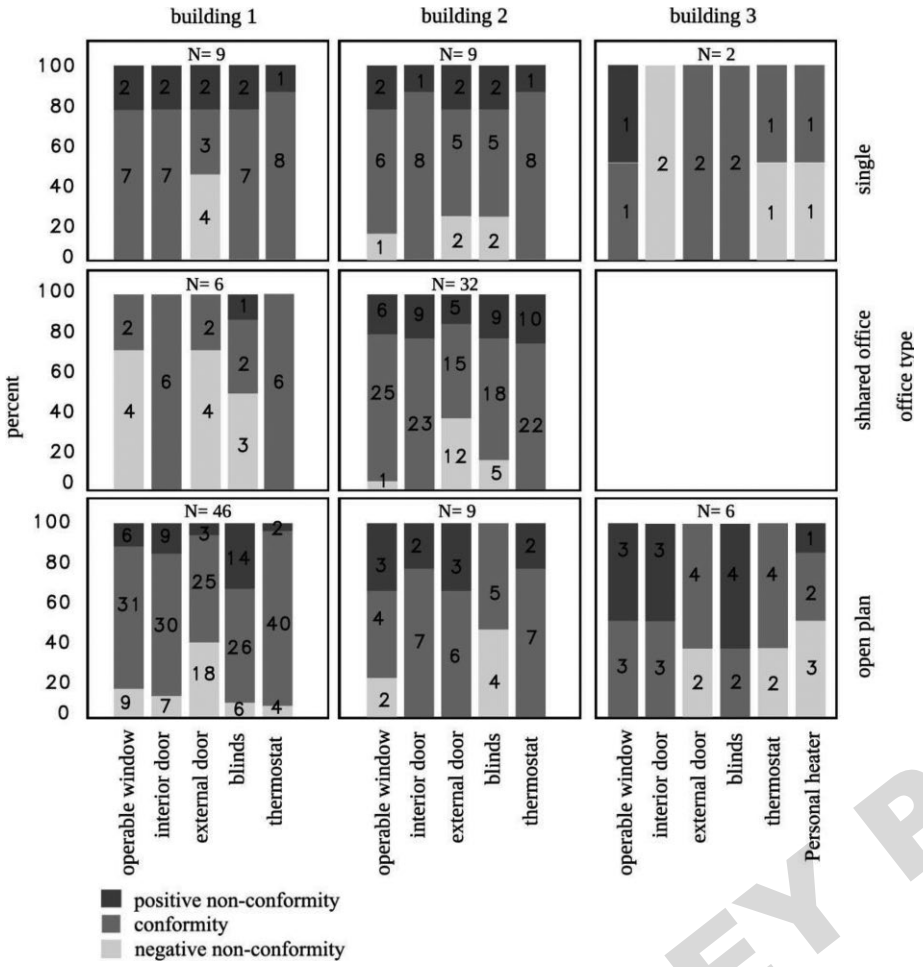


Fig. 8 Categories of conformity between perceived availability and desired controls in the three buildings. Numbers in the columns represent the total number of occupants.
Kategorien der Konformität (Übereinstimmung) zwischen wahrgenommener Verfügbarkeit von Kontroll- und Anpassungsmöglichkeiten und gewünschten Kontroll- und Anpassungsmöglichkeiten in den drei Gebäuden. Die Zahlen in den Säulen geben die Gesamtzahl der Nutzer an.

ii) '*not important*', with the following reasons: 'not worth asking others' permission' and 'not worth disturbing my work';
iii) '*no need to change*', with reasons: 'no need, co-worker did this', 'wanted to exhaust other control options first', and 'I was comfortable enough'.

The category '*no need to change*' was the most often stated category for not using indoor climate controls with 73 %, 79 % and 69 % in single, shared and open-plan offices respectively. The second prevalent category was related to '*no success expected*' with 16 %, 15 %, and 24 % in single, shared and open-plan offices respectively. The category '*not important*' was the least reported one with 11 %, 6 % and 7 % in single, shared and open-plan offices respectively. The results for the summer, autumn and winter seasons show a tendency similar to that found in spring's results. Overall, the majority of responses fall in the '*no need to change*' category, with the smallest percentage of 40 % during winter in-open plan offices. This percentage increased to 93 % for single offices in summer. The second category '*no success expected*' reflected the highest percentage of 54 % in open-plan offices in winter, while this percentage was 4 % in single offices in autumn. Answers related to '*not important*' were relatively few, with the highest percentage of 14 % in shared and open-plan offices during autumn.

Do the different categories of 'reasons for not exercising available adaptive controls' affect 'perceived control' Fig. 10? It was expected that those who answered in the category '*no success expected*' experienced a low level of perceived control in their offices. The analysis shows significant differences in the three categories' median of perceived control ($p < 0.05$) in all seasons. Comparing the two categories '*no success expected*' and '*no need to change*', the median of the perceived control score for the category 'no success expected' lies one unit lower in spring, autumn and winter. Pairwise tests were applied to analyse the differences between each two categories of 'reasons for not exercising available adaptive controls'. Significant differences appeared between '*no success expected*' and '*no need to change*' in all seasons, as well as between '*no success expected*' and '*not important*' in autumn. Whereas differences between '*not important*' and '*no need to change*' were not significant which is conform to expectation.

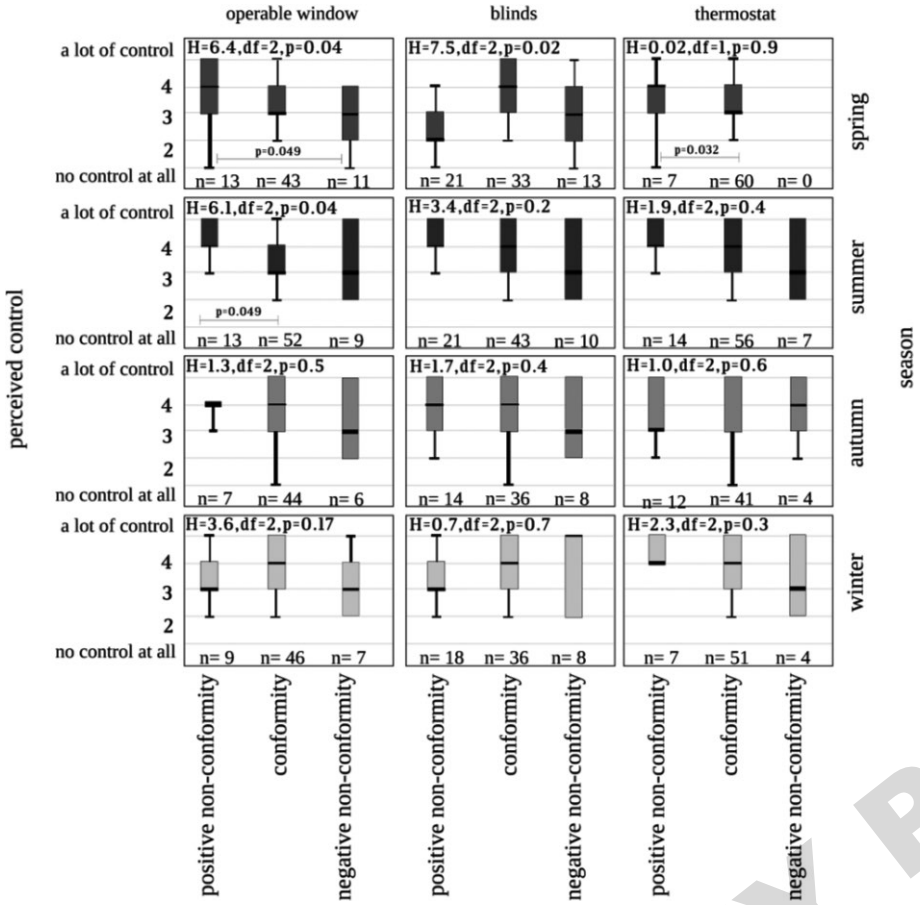


Fig. 9 Frequencies of perceived control votes for the three categories of conformity between perceived availability and desired controls. Analysis based on Kruskal-Wallis test ($\alpha = 0.05$). Numbers n refer to the number of occupants. Asymptotic significances (2-sided tests) are displayed. The significance level is 0.05. Probability values have been adjusted by Dunn-Bonferroni correction for multiple tests.
Häufigkeit der Antworten zur wahrgenommenen Kontrolle für die drei Kategorien der Konformität zwischen wahrgenommener Verfügbarkeit der Kontroll- und Anpassungsmöglichkeiten und gewünschten Kontroll- und Anpassungsmöglichkeiten. Die Analyse basiert auf dem Kruskal-Wallis-Test ($\alpha =$ 0,05). Die Zahlen *n* beziehen sich auf die Anzahl der Nutzer. Es werden asymptotische Signifikanzen (zweiseitige Tests) angezeigt. Das Signifikanzniveau beträgt 0,05. Die Signifikanzwerte wurden mit der Dunn-Bonferroni-Korrektur für Mehrfachtests angepasst.

4 Discussion

In this section we discuss first a) discuss methodological issues. Subsequently, we discuss b) the impact of season and privacy on perceived control and c) the preferred adaptive opportunities.

Furthermore, we discuss d) how knowledge and expectation impact the degree of control perceived, leading to e) reasons for not using adaptive opportunities. Finally, the authors point towards f) how personal control can be considered in building design and argue for g) formulating personal control as a requirement in indoor environment standards.

4.1 Methodological aspects

Our approach was to investigate naturally ventilated, non-air-conditioned office buildings in Amman [30]. However, it proved to be difficult to find free running buildings because most office buildings were found to rely on air conditioning. Thus, the study was adjusted by surveying two mixed-mode buildings and one free running building. Although the sample size of the free running building was rather small, we found it important to include this type of building in order to document the thermal comfort conditions, which can occur without using energy for conditioning.

In our longitudinal approach, we approached the subjects in every season 2 times a week over 2 to 3 weeks. On one hand this was necessary, on the other hand the questions on adaptive opportunities were quite comprehensive, and therefore it was somewhat challenging to maintain motivation of participants. We decided to ask for desired adaptive opportunities in the background questionnaire, hence only once. This might not have been sufficient as desires likewise perception might be influenced by the current inner stage of participants ([2]; Schweiker et al., 2020 [35]), and hence may depend on season. However, we choose to do so in order to limit the length of the questionnaire.

In this paper, we report on the self-reported use of adaptive opportunities. It would have been supportive to monitor real user behaviour. Limitations in the available instrumentation to monitor all windows, doors, blinds, ther-

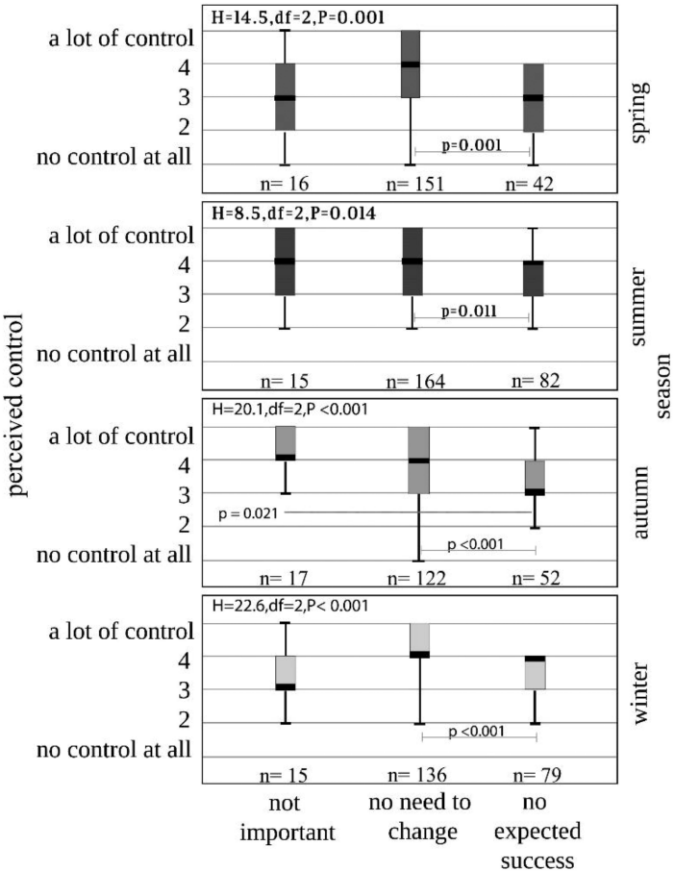


Fig. 10 Frequencies of perceived control votes for the three categories of 'reasons for not exercising available adaptive controls'. Analysis based on Kruskal-Wallis test ($\alpha = 0.05$). Numbers n refer to the number of occupants. Asymptotic significances ($\alpha = 0.05$, 2-sided tests) adjusted after Dunn-Bonferroni pairwise post-hoc tests of 'reasons for not exercising available adaptive controls'. Significant results are illustrated between the categories.
Häufigkeiten der Antworten zur wahrgenommenen Kontrolle für die drei Kategorien der ‚Gründe für die Nichtbenutzung verfügbarer Kontroll- und Anpassungsmöglichkeiten'. Die Analyse basiert auf dem Kruskal-Wallis-Test ($\alpha = 0{,}05$). Die Zahlen *n* beziehen sich auf die Anzahl der Nutzer. Asymptotische Signifikanzen ($\alpha = 0{,}05$; zweiseitige Tests) angepasst nach paarweisen Dunn-Bonferroni-Post-hoc-Tests der "Gründe für die Nichtbenutzung verfügbarer Kontroll- und Anpassungsmöglichkeiten". Signifikante Ergebnisse werden zwischen den Kategorien mit dem Signifikanzwert *p* gekennzeichnet.

mostats, etc. did not allow to do so. However, we determined in a simplified approach the frequency of decentralised air-conditioning ON stage when administering the questionnaires instead of measuring it (reported in [30]). This documentation supports the observation that thermostats (for the air-conditioning units) were used all year round, although with reduced usage in spring and autumn.

4.2 Seasonal and privacy aspects

No significant differences in perceived control level with regard to season were found, though the median of perceived control in spring was one scale point lower compared to the other seasons. This is in contrast to previous work (Gossauer and Wagner, 2007 [36]), which found that due to the reduced ability to influence the room temperatures in summer compared to winter in buildings without active conditioning in summer, perceived control over the room temperature was negatively affected in summer compared to winter.

It was observed that the mixed-mode buildings tended to provide larger office units. The majority of occupants in building 1 (75 %) worked in an open-plan office environments and in building 2 the majority (64 %) worked in shared offices. An open-plan layout is one of the most popular office designs in today's organisations (Samani, 2015 [37]). However, several studies indicate that the number of persons sharing one space decreases the level of control perceived (e.g. [8]; Duval, Charles and Veitch, 2002 [38]; Hauge, Thomsen and Berker, 2011 [39]; [28]). The occupants' perceived availability of all control options was lower in shared and open-plan offices compared to single offices in this study. Some occupants reported non-availability of operable windows and blinds in open-plan offices in both mixed mode buildings, although these opportunities were available.

4.3 Preferred adaptive opportunities

The most desired control options in this study were operable windows (77 % of the occupants) and thermostats (82 %). Leaman and Bordass, 2007 [40] suggest as a result of experience from numerous post-occupancy studies, that occupants' foregiveness is higher when the most desirable features, e.g. controls, are present. Hellwig [7] argues that these are the features the occupants are likely to use and are capable to use, and this would lead to a positive perception of self-efficacy. The least desired control options in the mixed-mode buildings were personal fans and heaters. It could be ask whether a similar evaluation would apply to newer technology of personalised comfort systems (PCS).

However, occupants had the opportunity to adjust thermostats of the decentralised split units, which offer a fast response towards the preferred indoor thermal conditions. Such options were desired by occupants in the free running building, who experienced especially in winter situations slightly outside their comfort range as reported elsewhere [30].

4.4 Knowledge and expectation of adaptive opportunities

New variables have been introduced in this study: *consistency of perceived and objective availability of controls* and *conformity to expectation of controls*. The first one can be interpreted as a proxy for the knowledge about available opportunities the occupants have. The second serves to characterise whether the building's indoor environmental affordances comply with the expectations of the occupants. *Knowledge* of potential personal control

strategies contributes to build *indoor environmental self-efficacy* ([7]; Hawighorst, Schweiker and Wagner, 2016 [41], one influencing variable of perceived control. In our study, the vast majority of votes showed consistency of objective and perceived availability of control. This means that the majority was aware of the adaptive opportunities available at their workplace. Although votes expressing perceived restrictions in accessing controls showed a one scale point lower level of perceived control (Fig. 7), the median difference was not significant, maybe due to the overall low proportion of occupants (13 %) expressing perceived restrictions. Hence, in buildings with less clearly understandable adaptive opportunities, the result could be different.

Conformity to expectation of control is seen as part of a person's evaluation system for judging the indoor environment ([7]) and herewith contributing to the level of control perceived. An expectation, which is not met by a building, can impact perceived control. The majority of votes demonstrated *conformity to expectation*. This means that the expectation of the majority towards control was met. Less than 14 % of the votes expressed a non-conformity to expectation, meaning that their expectation was not met. Votes expressing negative non-conformity led to a one scale point lower level of perceived control compared to all other votes for most adaptive opportunities in all seasons (Fig. 9). The median difference of perceived control of conformity to expectation was significant for operable windows in spring, summer and all seasons, as well as for blinds in spring. For thermostats, the overall number of participants reporting the lack thermostats was very low, probably contributing to a non-significant effect.

4.5 Reasons for not using adaptive opportunities

The reasons for not exercising available adaptive controls were divided into three main categories: 'no success expected', 'not important' and 'no need to change'. Significant differences were found in all seasons between 'no success expected' and the other two categories (Fig. 10). The reply 'no success expected' can be interpreted as a perceived constraint, addressing either a limitation in adjustability of the building or space ('would not have helped', 'cannot adjust option any further') or a constraint requiring negotiation with others: 'was not agreeable to others in the space' – as investigated experimentally by Schweiker and Wagner [28] and found in our study in shared and open-plan offices or 'not sure if it would be OK with management' – expressing an *external locus of indoor environmental control* as introduced in the conceptual model of perceived control ([7]) or indirect control as explained by Johnson, 1974 [42]. The ability of occupants in open-plan offices to control their work environment is more likely to be subject of perceived restrictions, as it is affected by both physical and psychological aspects, such as the need for prior negotiation, the location of the available control option in relation to occupants' workspace and how to reach it e.g. ([8]; [37]; [28]).

However, the most prevalent control exercise was 'no adjustment', which is reflected in the overall high percentage of comfortable votes (92 %). Even if 'no adjustments' were made most of the time, this would not justify reducing the availability of adaptive control opportunities, as availability, hence having opportunity is an important positive feature contributing to comfort perception ([6]; [7]). Beyond the use of the adaptive opportunities the building or building service systems afford, the occupants used also clothing adjustment which we have reported in [30].

4.6 Personal control in building design

When analysing the objectively available controls in this study, an inconsistent pattern was observed: sometimes it was not clear why an office did not afford e.g. an operable window whereas the other offices in the same building did. For example, the single offices of the surveyed buildings offered more objectively available control options compared to shared and open-plan offices. Non-operable windows were found in three shared offices in both buildings 1 and 2, and in two open-plan offices in building 1. This is surprising, as both buildings are LEED certified, aiming for high occupant comfort and satisfaction. Indoor environmental quality is a main section of the LEED scorecard ('LEED BD+C: New Construction (v2.2)', 2008 [43]; LEED BD+C: New construction v3, 2009 [44]), which includes the category of providing controllability over thermal comfort systems. The point related to this category was awarded for building 2, while it was not achieved in building 1. LEED certified buildings must achieve a certain number of points, depending on the specific rating system. However, it is not a must to fulfil all the indoor environmental quality criteria, which leaves the decision to include these points to the designer and owners of the buildings. This calls for a more conscious and intentional planning of indoor environmental affordances of buildings and specifically of each office within a building. Such planning procedure, supporting intentional planning of personal control was proposed in Hellwig et al. [20], [45], [46]).

4.7 Personal control as a requirement

The level of thermal comfort and good perception of indoor air quality was in general high in the buildings investigated. Our previous analysis ([30]) showed that room temperatures of the discomfort group were not different from the comfort group and hence cannot provide a straight forward explanation for discomfort expressions. A lower level of perceived control was identified to characterise those, not feeling comfortable. Although not the focus of this study, it once again confirms, the strong correlation between perceived control and indoor climate

perception, which has been a consistent result throughout numerous studies (e.g. [23]; [8]; [9]; [26]; [15]; Kwon et al., 2019 [47]; Sakellaris et al., 2019 [48]). Therefore, behaviour (option) was already early regarded as an essential component to comprehensive comfort evaluation ([1]; [2]; [3]). Later, researchers proposed to make personal control classification part of standards on indoor environment requirements (Boerstra, 2010 [49]; [7]). However, a simplified approach was only integrated into the Dutch comfort standard ISSO 74 (van der Linden et al., 2006 [50]; Boerstra, van Hoof and van Weele, 2015 [51]). The difficulty, why personal control is still not implemented in requirements in standards might be found in the fact that quantitative requirements are easy to be implemented in standards compared to such qualitative factors like personal control.

5 Conclusion

The main objective of this study was to shed more light on the perception of control at office workplaces. For this we analysed objectively available adaptive opportunities; individual perception of their availability; occupants' desire for certain adaptive opportunities; how often and which controls were exercised; and reasons for not exercising available adaptive opportunities.

These results of this study are based on the confirmation of a results found in numerous studies before: the level of personal control perceived by occupants correlates with indoor climate perception positively. Another result from previous studies was also confirmed in this study: the level of personal control perceived is higher in smaller office units, hence when more privacy is available for occupants.

Hence, one study more confirming that from the viewpoint of occupants' indoor climate satisfaction, open-plan offices are the least desirable floor plan solution. It can be ask when finally those numerous confirmations of this effect will be accepted and answered by more suitable office layout concepts.

The effect of season on the level of perceived control found in previous studies could not be confirmed, possible methodological reason for this we have discussed.

In this study, we introduced two new variables: i) consistency of perception of controls and ii) conformity to expectation of controls. The hypothesised correlation with the level of personal control perceived could only be confirmed for conformity to expectation of controls. However, it is recommended for future research that the construct of the variable *consistency of available and perceived controls*, is investigated with less usable controls than in this study in order to test the knowledge or skills of the occupants or to investigate perceived restrictions. We could show by using the variable *conformity of expectation of controls*, that control expectation of the occupants needs to be considered in the design and operation of buildings calling for an occupant centric approach. Although further work is required, our results support the important role of the match between expectation and reality on the degree of perceived control. Thus, availability of many adaptive opportunities in buildings can positively affect occupants' comfort perception but matching expectations appears to be of equivalent importance. Particularly, this study confirms that operable windows are a highly desired interface feature of workspaces. Buildings should therefore preferably be designed with operable windows.

Besides that there exists a proposal for a planning procedure for adaptive control opportunities (see discussion), we have discussed to introduce the need for personal control as a mandatory requirement for usable buildings' indoor environmental design in indoor environmental quality standards, which also need to describe minimum requirements for occupant interfaces.

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Declaration of interest statement

The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

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Authors
Dr.-Ing. Farah Z. Al-Atrash (corresponding author)
farah.alatrash@gju.edu.jo
German Jordanian University
Darat Othman Bdeir
School of Architecture and Built Environment
Architecture and Interior Architecture Department
P.O. Box 35247
Amman 11180/Jordan

Prof. Dr.-Ing. Runa T. Hellwig
rthe@create.aau.dk
Aalborg University
Department of Architecture, Design and Media Technology
Section for Architecture and Urban Design
Rendsburggade 14
9000 Aalborg/Denmark

Prof. Andreas Wagner
wagner@kit.edu
Karlsruhe Institute of Technology (KIT)
Institute for Building Design and Technology
Building Science Group (fbta)
Englerstr. 7
76131 Karlsruhe/Germany

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Appendix I

Available controls, perceived control and desired control in offices of the three buildings. Numbers for available control refer to number of offices. Numbers for perceived control and desired control refer to number of persons. Adjusted after [34].
Verfügbare Kontroll- und Anpassungsmöglichkeiten, wahrgenommene Kontrolle und gewünschte Kontroll- und Anpassungsmöglichkeiten in den Büros der drei betrachteten Gebäude. Die Angaben für die verfügbare Steuerung beziehen sich auf die Anzahl der Büros. Die Angaben für die wahrgenommene und die gewünschte Steuerung beziehen sich auf die Anzahl der Personen. Angepasst nach [34].

Building 1

	available controls		**perceived availability of controls**		**desired controls**		
	yes	**no**	**yes**	**no**	**yes**	**no**	
operable windows	9	0	9	0	7	2	Single office (9 persons)
interior door	9	0	9	0	7	2	
exterior door	1	8	3	6	5	4	
blinds	9	0	9	0	7	2	
Thermostat	9	0	9	0	8	1	
personal fan	0	9	0	9	1	8	
personal heater	0	9	0	9	1	8	
operable windows	0	3	2	4	6	0	Shared office (3 offices, 6 persons)
interior door	3	0	6	0	6	0	
exterior door	0	3	1	5	5	1	
blinds	0	3	2	4	4	2	
Thermostat	3	0	6	0	6	0	
personal fan	0	3	0	6	0	6	
personal heater	0	3	0	6	0	6	
operable windows	6	2	34	12	37	9	Open office (8 offices, 46 persons)
interior door	7	1	28	18	26	20	
exterior door	1	7	12	34	27	19	
blinds	6	2	32	14	24	22	
Thermostat	8	0	38	8	40	6	
personal fan	0	8	0	46	20	26	
personal heater	0	8	0	46	19	27	

Building 2

	available controls		perceived availability of controls	desired controls		
	yes	**no**	**yes**	**yes**	**no**	**yes**	
operable windows	7	1	8	1	7	2	Single office (8 offices, 9 persons as the occupancy changed)
interior door	8	0	8	1	7	2	
exterior door	0	8	4	5	4	5	
blinds	6	2	5	4	5	4	
Thermostat	8	0	9	0	8	1	
personal fan	0	8	0	9	2	7	
personal heater	0	8	0	9	2	7	
operable windows	7	3	31	1	26	6	Shared office (10 offices, 32 persons)
interior door	10	0	32	0	23	9	
exterior door	2	8	14	18	21	11	
blinds	7	3	27	5	23	9	
Thermostat	10	0	31	1	21	11	
personal fan	1	9	1	31	10	22	
personal heater	0	10	1	31	9	23	
operable windows	2	0	5	4	4	5	Open office (2 offices, 9 persons)
interior door	2	0	9	0	7	2	
exterior door	2	0	9	0	6	3	
blinds	0	2	2	7	6	3	
Thermostat	2	0	9	0	7	2	
personal fan	0	2	0	9	4	5	
personal heater	0	2	0	9	3	6	

Building 3

	available controls		perceived availability of controls	desired controls		
	yes	**no**	**yes**	**yes**	**no**	**yes**	
operable windows	1	0	2	0	1	1	Single office (1 office, 2 persons as the occupancy changed)
interior door	0	1	0	2	2	0	
exterior door	1	0	2	0	2	0	
blinds	1	0	2	0	2	0	
Thermostat	0	1	-	-	2	0	
personal fan	1	0	1	1	2	0	
personal heater	1	0	1	1	2	0	
operable windows	1	0	6		3	3	Open office (1 office, 6 persons)
interior door	1	0	6	0	3	3	
exterior door	0	1	0	6	2	4	
blinds	1	0	6	0	2	4	
Thermostat	0	1	-	-	6	0	
personal fan	0	1	0	6	2	4	
personal heater	1	0	1	5	3	3	