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The Impact of Façade Renovation Strategies on User Satisfaction in Offices:
Case Studies for Summer in the Netherlands

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ABSTRACT: Many offices have been renovated to improve building performance. However, the user's perception after renovation has not been evaluated. This paper presents user satisfaction with indoor environmental quality in façade renovated offices in the Netherlands. The study explored the correlation between facade renovation strategies and indoor climate on the one hand and on the other hand user satisfaction and user preferences. Data were collected in four renovated offices in the Netherlands, which were adapted using different façade renovation strategies. The case study consisted of conducting online surveys and indoor climate monitoring for 2 weeks with loggers. Statistical results demonstrate that design factors such as desk location, workplace orientation, and layout have a strong correlation with user satisfaction of IEQ, unlike window types. The suggested essential design factors for user satisfaction can guide architects and designers to better understand users' preferences and to reflect on office design.
KEYWORDS: User satisfaction, Office renovation, Façade renovation, Indoor climate

1. INTRODUCTION

Refurbishing façades is an essential building renovation solution for reducing energy demand. Often, the objective of the building renovation is to reduce energy demand with low investment costs. However, next to economic and environmental impacts of energy renovation, social impact is also important [1] to encourage energy renovation. However, the energy renovation should not only consider the energy performance but also user satisfaction, as higher user satisfaction increases the value of buildings [2]. Although we expect that renovated office buildings will provide improved building conditions in various perspectives, there are a few cases reported with low levels of indoor environmental satisfaction in energy efficient buildings [3].

The facade quality strongly relates to indoor climate, since the façade controls the amount of light, ventilation and temperature. Moreover, indoor climate has high impact on thermal comfort. The thermal comfort is one of the important parameters in the building design [4] that mainly contributes to increase user satisfaction. For this reason, this paper compares the indoor climate of renovated offices, which applied different renovation strategies to user satisfaction. This leads to the following research question: how does the façade strategies affect user satisfaction?

2. METHODS

To conduct this study, five renovated office buildings were studied, from which three types of datasets were collected. The degree of renovation was classified by [5-7] The methodological approach was developed based on [8]. First, technical information related to façade renovation was collected. Second, monitoring actual indoor climate was conducted during summer (e.g., temperature, relative humidity (RH), and illuminance). Last, a user satisfaction survey was distributed to the office occupants by online and paper means. SPSS was used to scrutinise the correlation between façade types on user satisfaction and understand the correlation between indoor climate and user satisfaction.

There were three conditions to select the case studies. The selected five offices are located in the Netherlands, originally built in the 1960s to 1980s. The energy label of these buildings improved from F or G to A after renovation. Different façade strategies were applied to the offices, from passive to active. All the case studies were occupied at least over a couple of years after renovation, thereby they can provide one-year energy use data.

Renovated offices have climate ceiling for heating, cooling, and ventilation with central control mechanical system. In addition, each workplace has thermostat. Non-renovated office has decentralised heating system and no ventilation system is installed.

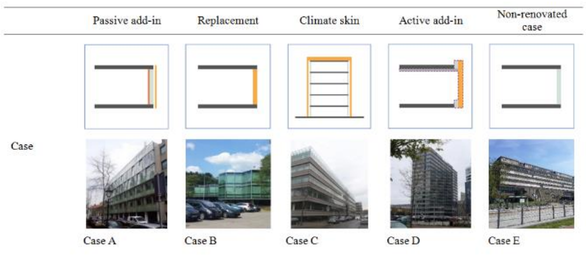


Figure 1: Different scale of façade renovation strategies

2.1 Indoor climate measurements

Indoor climate was monitored for two weeks in July to avoid significant climate variations during summer. Measurement time was started and ended at the same time and date. HOBO loggers, which monitor temperature, RH, and illuminance were placed in workplaces with different orientations. The devices were positioned to collect the data at 0.9m height desks from the floor. Table 1 shows the placed location of devices in five case studies. One logger was placed in each orientation. Outdoor climate was taken from local meteorological stations near the buildings.

Table 1: Measurement locations in five cases

Renovation strategies	Orientations			
	N.E	N.W	S.E	S.W
Passive add-in	*	*	*	*
Replacement	*			*
Climate skin	*	*	*	*
Active add-in	*			*
Non-renovated case		*	*	

2.2 User satisfaction survey

A modified questionnaire is developed based on literature [9-11]. The modified version has 38 questions consisting of three chapters: general information, indoor environmental quality, and functional quality and user perception. In this paper, we only focused on user perception about indoor comfort. The questionnaires consist of three parts: general information, indoor environmental quality, and user's perceptions. Each option was allocated a score: 1= extremely dissatisfied, 2= somewhat satisfied, 3= neither dissatisfied nor satisfied, 4= somewhat satisfied, and 5= extremely dissatisfied. Respondents were asked to rate their satisfaction on a five-point Likert scale regarding environmental variables such as temperature, air quality, humidity and overall comfort.

Only 14 (2.2%) people have their own room. Among cellular office rooms, sharing workplace with 2-3 people was common type with 93 (14.6 %). 53 people (8.3%) of total participants shared the workplace with 4-6 collegues. Majority of people (56.2%) work in open space with over 10 colleagues.

2.3 Analysis

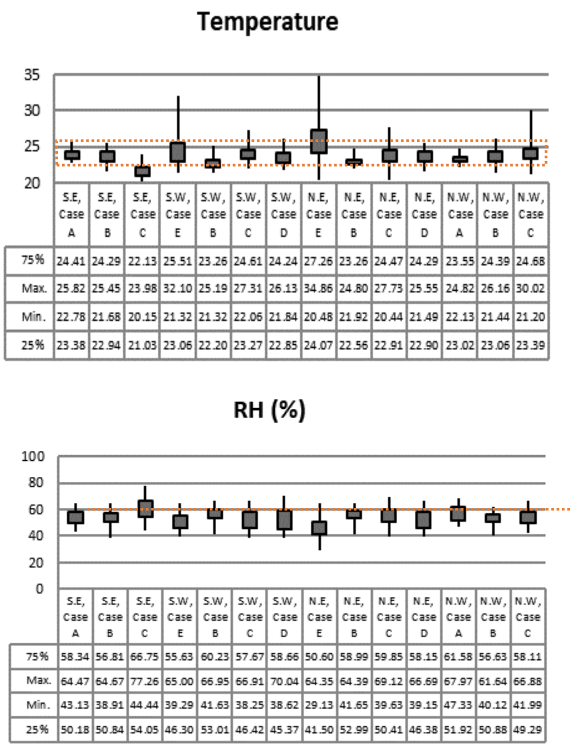
IEQ data were stored in SPSS Statistics 24.0 and examined using descriptive statistics showing minimum, maximum, mean value and standard deviation (SD). The characteristics of indoor climate of each office were summarized. After that, the data were compared to outdoor climate information to check how well each office has managed indoor climate quality.

To examine the relationship between design factors and user satisfaction of indoor comfort, statistical analysis was performed. The dependent variable was user satisfaction, and independent variable was design factors. The selected significance level was p = 0.05. The measurements were ordinal level, and the values were not equally distributed. Thus, Spearman's correlation coefficient, which is for nominal variables, was used to determine correlations between variables regarding user satisfactions and design factors. The test shows both frequency of votes and rates for each office and makes it easy to compare the satisfaction level. Multi linear and binary logistic regression were performed to sort out which of the predictor variables do have an impact on the dependent variable, and which factors matter the most.

3. Results

3.1 Indoor climate data

The measured indoor climate data represent temperature, RH, and lighting of workplaces located in different orientations and offices (*Fig. 1*). These data were collected to compare indoor environmental quality of different orientations in a building and the same orientations of different office buildings. The orange colour in figure 2 pictures comfort zone recommended by the NEN 15251 standard. The result shows that the non-renovated office (Case E) has poor indoor environmental quality, and the temperature is quite high compared to renovated offices. In case C, workspace with a south-east orientation was cooler than set by the guideline. Nevertheless, the RH (%) values of five buildings are in the comfort zone except for the S.E workplaces from case C. Workspace on the north side was tending to be warmer than on the south side.



	S.E, Case A	S.E, Case B	S.E, Case C	S.W, Case E	S.W, Case B	S.W, Case C	S.W, Case D	N.E, Case E	N.E, Case B	N.E, Case C	N.E, Case D	N.W, Case A	N.W, Case B	N.W, Case C
75%	24.41	24.29	22.13	25.51	23.26	24.61	24.24	27.26	23.26	24.47	24.29	23.55	24.39	24.68
Max.	25.82	25.45	23.98	32.10	25.19	27.31	26.13	34.86	24.80	27.73	25.55	24.82	26.16	30.02
Min.	22.78	21.68	20.15	21.32	21.32	22.06	21.84	20.48	21.92	20.44	21.49	22.13	21.44	21.20
25%	23.38	22.94	21.03	23.06	22.20	23.27	22.85	24.07	22.56	22.91	22.90	23.02	23.06	23.39

	S.E, Case A	S.E, Case B	S.E, Case C	S.W, Case E	S.W, Case B	S.W, Case C	S.W, Case D	N.E, Case E	N.E, Case B	N.E, Case C	N.E, Case D	N.W, Case A	N.W, Case B	N.W, Case C
75%	58.34	56.81	66.75	55.63	60.23	57.67	58.66	50.60	58.99	59.85	58.15	61.58	56.63	58.11
Max.	64.47	64.67	77.26	65.00	66.95	66.91	70.04	64.35	64.39	69.12	66.69	67.97	61.64	66.88
Min.	43.13	38.91	44.44	39.29	41.63	38.25	38.62	29.13	41.65	39.63	39.15	47.33	40.12	41.99
25%	50.18	50.84	54.05	46.30	53.01	46.42	45.37	41.50	52.99	50.41	46.38	51.92	50.88	49.29

Figure 2: Comparison of the measured indoor climate (temperature, relative humidity) in five offices

3.2 User perception about indoor climate

Figure 3 illustrates a comparison of how occupants perceive the temperature. The perception was marked with five options: cold, cool, comfortable, warm and hot. Over 60 percent of the occupants from the A, B, and C offices indicated that they felt comfortable with the temperature and feeling warm was the second most frequent answer. Although case D had a well-controlled indoor climate, around 30 percent of the users answered they felt cold in summer. In case E, people tended to feel warmer and hotter, and few people answered they felt cold. This shows that the percentage of temperature within the guideline range is not the only factor that influences user perception, and it is risky to say that people working in recommended/guideline climate zone always feel comfortable. Especially, in case of the D office, it is important to do further research by considering other variables such as how far the occupants sit from a window, orientation of workspaces, and office layouts etc.

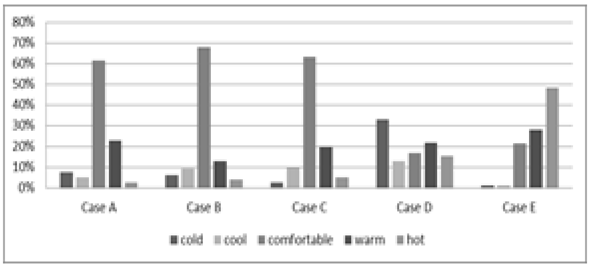
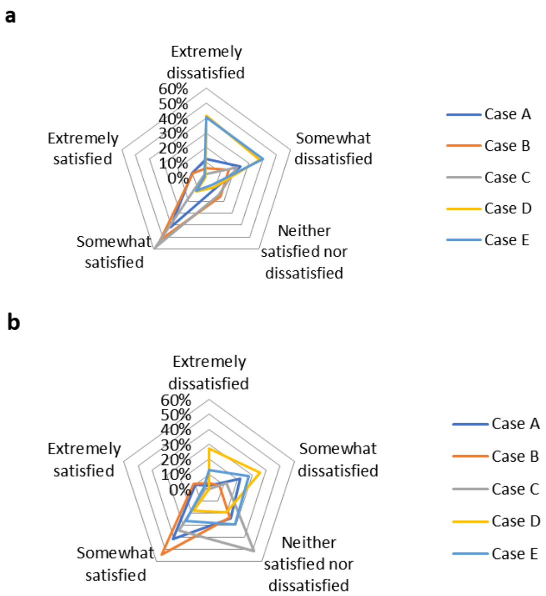


Figure 3: User perception of indoor temperature for five cases

3.3 User satisfaction in summer

738 occupants from 5 buildings responded to the user satisfaction survey. The occupants consist of around 70% full-time and 30% part-time employees. 549 of total respondents completed the survey.



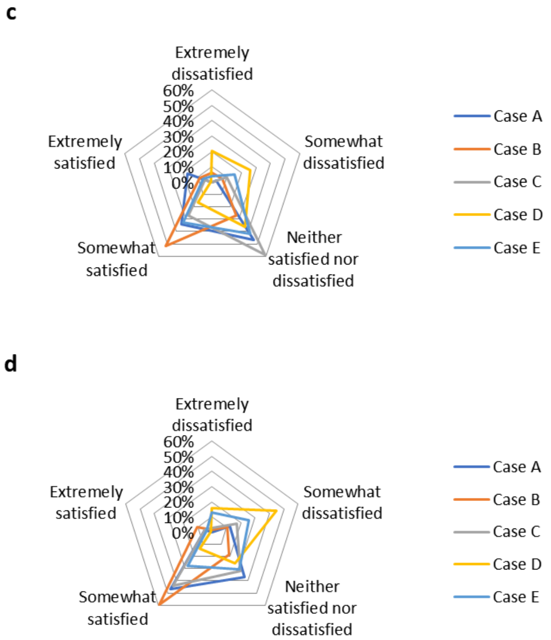


Figure 4: Comparison of user satisfaction in five cases a. Temperature, b. Air quality, c. Humidity, and d. Overall comfort.

In order to compare user's perception and actual indoor climate, the survey included to what extent people were satisfied with the following categories (e.g., temperature, air quality, humidity and overall comfort) in summer. Overall, occupants working in case A and B were more satisfied in terms of temperature, air quality, humidity and overall comfort than in case C, D, and E (Figure 4). Only in case of humidity, most people from case A were neither satisfied nor dissatisfied. People from case C, D, and E had more neutral satisfaction. At the same time, case C and E showed high percentage of dissatisfaction with the temperature. Thus, it is evident that people are more satisfied with indoor climate in case A, B, and C than D, and E. Moreover, case E provided unpleasant indoor environmental quality.

Table 2: Density of workplace of each case

		Office					
		A	B	C	D	E	Total
Number of colleagues sharing the room	Alone	7	2	0	2	3	14
		17.9%	1.5%	0.0%	0.8%	4.0%	2.6%
	2-3 people	29	2	13	11	38	93
		74.4%	1.5%	31.7%	4.2%	50.7%	16.9%
	4-6 people	1	4	13	12	23	53
		2.6%	3.0%	31.7%	4.6%	30.7%	9.7%
	7-9 people	0	1	6	19	5	31
		0.0%	0.8%	14.6%	7.3%	6.7%	5.6%

	over 10	2	124	9	217	6	358
		5.1%	93.2 %	22.0 %	83.1 %	8.0 %	65.2%
Total		39	133	41	261	75	549

Results of the Spearman correlation indicated that there was a moderate correlation between different façade strategies and satisfaction of indoor climate in summer. Desk location and user satisfaction with temperature, air quality, humidity and overall comfort were significantly correlated. In other words, desk location is an important factor to increase occupants' satisfaction. On the contrary, there was a weak positive correlation between orientation and temperature. Window types affected most user satisfaction variables except for satisfaction with humidity. Office layout only affected user satisfaction of temperature and overall comfort.

Although we could find the correlation between dependent and independent variables, the precise information such as in which design options people were highly satisfied within those independent variables need to be analysed further.

Table 3: Correlation between design factors and user satisfaction on indoor climate

		Temperature	Air quality	Humidity	Overall comfort
Desk location	CC	0.135**	0.133**	0.138**	0.175**
	p-value	0.001	0.001	0.001	0.000
Facade types	CC	0.110**	0.086*	0.043	0.113**
	p-value	0.009	0.040	0.302	0.007
Orientation	CC	0.089*	0.057	0.028	0.072
	p-value	0.032	0.168	0.494	0.084
Layout	CC	0.142**	0.065	0.057	0.112**
	p-value	0.001	0.129	0.184	0.008

*p <.05; **p <.01; ***p <.001.
CC: Correlation Coefficient

A multiple linear regression analysis was performed to determine the orientation of workspace, desk location, window types, and layout to predict the user satisfaction with IEQ. Preliminary analyses were performed to ensure whether the assumption of normality and multicollinearity were validated.

In order to conduct the regression analysis, non-parametric measures were translated to dummies. The last dummy was a standard for each variable group (desk location over 4m, over 70% of glazing area, north-west orientation, and Flex-office layout).

Table 4 represents influential variables mathematically sorted out for satisfaction with indoor climate. Variables with over 10 of Variance Inflation Factor (VIF) were eliminated due to multicollinearity. R^2 explains estimation of the strength of the relationship between the model and the response variables. The regression models with sorted independent variables satisfied p-value < 0.05, which means statistically significant. Orientation only affected temperature satisfaction. The results from multi-linear regression demonstrated that desk location is the only factor influencing satisfaction on air quality and humidity. In detail, people who sit far away from windows were inclined to be satisfied with IEQ. A desk location of 0-2m away from windows had a strong negative impact on user satisfaction in terms of temperature, air quality, humidity and overall comfort, while, people sitting over 4m away from windows were significantly satisfied with the indoor climate. Facades with 30 % of glazing area were eliminated due to high *p*-value.

People sitting on the south-west side were the most dissatisfied with the temperature followed by workplaces on the north-east side. People working in open plan offices represented a strong dissatisfaction with temperature and overall comfort. On the other hand, people working in flexible offices were more satisfied. Therefore, a desk location over 4 m away from windows, north-west oriented workspace, and flexible office layout could be an optimal design to increase user satisfaction on indoor climate.

Table 4: User satisfaction with indoor environmental parameters and building features that correlated based on from multi linear regression analysis

Satisfaction	Independent variable	B	β	p-value	VIF	Durbin-Watson	R^2
Temperature	Constant	3.101		0.000		1.513	0.043
	Desk location 0-2m	-0.770	-0.307	0.000	2.290		
	Desk location 2-4m	-0.757	-0.279	0.000	2.290		
	Constant	1.806		0.000		1.487	0.014
	Façade (50% glazing)	-0.222	-0.113	0.008	1.045		
	Constant	3.074		0.000		1.577	0.055
	Orientation S.E	-0.430	-0.122	0.000	1.631		
	Orientation S.W	-0.809	-0.317	0.000	2.079		
	Orientation N.E	-0.752	-0.270	0.000	1.965		
	Constant	2.910		0.000		1.483	0.033
	Cellular	-0.518	-0.157	0.002	1.478		
	Open	-0.572	-0.227	0.000	1.616		
	Combi	-0.490	-0.112	0.019	1.282		
Air quality	Constant	3.329		0.000		1.639	0.035
	Desk location 0-2m	-0.646	-0.278	0.000	2.290		
	Desk location 2-4m	-0.624	-0.249	0.000	2.290		
	Constant					1.648	0.033
	Orientation S.W	-0.502	-0.211	0.000	1.369		
	Orientation N.E	-0.352	-0.136	0.005	1.369		
Humidity	Constant	3.367		0.000		1.697	0.025
	Desk location 0-2m	-0.515	-0.241	0.000	2.290		
	Desk location 2-4m	-0.428	-0.185	0.003	2.290		
	Constant	3.197		0.000		1.667	0.022
	Orientation S.W	-0.362	-0.166	0.001	0.731		
	Orientation N.E	-0.307	-0.129	0.007	0.731		
Overall comfort	Constant	3.380		0.000		1.547	0.041
	Desk location 0-2m	-0.655	-0.305	0.000	2.290		
	Desk location 2-4m	-0.519	-0.223	0.000	2.290		
	Constant	3.009		0.000		1.386	0.018
	Façade (50% glazing)	-0.318	-0.136	0.001	1.045		
	Constant	3.238		0.000		1.434	0.031
	Cellular	-0.320	-0.113	0.028	1.478		
	Open	-0.480	-0.222	0.000	1.616		
	Combi	-0.438	-0.116	0.015	1.282		

To summarise, optimal user satisfaction value for the statistic model follows the formula below:

Temperature

Y = 3.101 -0.770*(Desk location 0-2m) -0.757*(Desk location 2-4m)
Y = 1.806 -0.222*(Façade (50% glazing))
Y= 3.074 -0.430*(S.E) -0.809*(S.W) - 0.752*(N.E)
Y= 2.910 -0.518*(Cellular) -0.572*(Open) -0.490*(Combi)

Air quality

Y = 3.329 -0.646*(Desk location 0-2m) -0.624*(Desk location 2-4m)

Humidity

Y = 3.367 -0.515*(Desk location 0-2m) -0.428*(Desk location 2-4m)

Overall comfort

Y = 3.380 -0.655*(Desk location 0-2m) -0.519*(Desk location 2-4m)
Y = 3.009 -0.318*(Window types 50%)
Y= 3.238 -0.320*(Cellular) -0.480*(Open) -0.438*(Combi)

4. CONCLUSION

This study investigated the impact of façade strategies on user satisfaction during summer in the Netherlands. First, an indoor temperature according to the guideline (NEN 15251) did not always result in higher user satisfaction. For example, the office with active façade renovation/high-tech renovation (case D) was qualified comfortable indoor environment according to the guideline. The occupants were, however, considerably dissatisfied with the indoor climate. There was a big difference in satisfaction with temperature between the non- renovated case and the renovated office cases in this study. The occupants were more sensitive to temperature than to relative humidity (see Fig. 4-c). Furthermore, people had more complaints about temperature than other indoor climate factors. Still, there may be more reasons why people feel dissatisfied with the indoor climate next to temperature, air quality and RH.

Second, we could find correlations between each variable group through the Spearman test. The regression analysis, however, showed slightly different results than the correlation results. In the Spearman test, orientation was the relatively less important factor for user satisfaction among the four categories. In contrast, orientation was an influential factor to air quality and humidity as well as temperature in the multi-linear regression analysis. South-east variable was automatically eliminated from the independent variables during the analysis, as the orientation was not statistically significant. On the other hand, desk location was the most influential factor for user satisfaction according to the both analysis methods. Different glazing area of façade was correlated to temperature and overall comfort.

Lastly, we could assume the tendency of user satisfaction with different design factors. People tended to be more satisfied when they sit far away from window and with large glazing area in north-west orientation in flexible office layout.

Nevertheless, finalising a decision for the façade renovation needs to include various factors, not only techniques but also the design quality and the way of use. The next step of the study will deal with visual-related variables such as the view to the outside, daylighting, and artificial lighting, and will include the data about winter and moderate seasons.

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