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Perceived Acoustic Quality and Effect on Occupants' Satisfaction in Green and Conventional Residential Buildings

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Received: 26 December 2018; Accepted: 11 January 2019; Published: 18 January 2019

Abstract: The study presented in this paper focuses on the subjective opinions of occupants of multistory residential buildings by examining the relationship between occupants' satisfaction and indoor environment quality, and analysing the effect the problems experienced with noise level may have on general satisfaction and the perceived acoustic quality. The analysis is based on data collected through surveys addressed to adults living in green and conventional buildings. The results show that occupants are very satisfied with their apartments, and subjectively rated acoustic quality received very high scores. The responses indicate that noise from neighbours has been experienced relatively seldom by occupants; however, the analysis shows that it is the factor that has the strongest effect on satisfaction with acoustic quality. We have found that the environmental profile of a building has a significant effect on general satisfaction expressed by occupants; however, this effect has not been confirmed for acoustic quality.

Keywords: green building; acoustic comfort; noise; occupant satisfaction; IEQ

1. Introduction

For years, the research community has argued about the negative effects of chronic exposure to noise and warned that it may cause annoyance, significantly affect sleep patterns, and even lead to serious health problems [1]. For example, findings from a study conducted across eight European countries suggest that frustration caused by neighbours' noise increases the risk of health deterioration [2].

Moreover, the literature gives many empirical examples of outdoor noise levels having an effect on housing market prices; for example, Wilhelmsson [3] found that the price of single-family houses decreased by 0.3–3% per dB. Negative effects on dwelling prices due to noise level were found in studies conducted in Germany [4], Poland [5], Korea [6] and the United States [7].

The challenge in studying acoustic quality in the built environment is that it can be affected by different factors, from building location [8] and city design [9] to building design [10–12], vegetation included on the building facade [13], construction type [14], balcony types [15], and choice of material and construction elements [16].

Gozalo et al. [17] refer to three main approaches applied in studying acoustic quality in the built environment: physical, psychophysical and perceptual. The aim of the physical approach is objectivity attained by measurements and referral to regulations and guidelines. Even though measurements are perceived as the source of objectivity in the studies, variations in results are notorious. Scrosati and Scamoni [18] profoundly discussed problems with measurements and uncertainty in acoustics studies. The second approach (psychophysical) introduces the subjective opinion of the recipients of sound and cross-analyzes responses with on-site measurements, while the third approach focuses on the correlation between environment and people, targeting the cognitive process of sound appraisal [17].

The results from subjective ratings of noises can vary depending on the studied frequencies, the design of the experiment, the length of time over which the data is gathered and the presence of other noises that may occur in the dwellings in their normal setting [14]. Hongisto et al. [14] discuss a study by Mortensen, who found through laboratory experiment that noise from neighbours transmitted through light walls was rated as more annoying than noise transmitted through a heavy wall (as cited in [14]). However, results suggest that sound carried through heavy constructions was rated as louder (as cited in [14]). Hongisto et al. [14] compared acoustic satisfaction in multistory residential buildings with heavy and light walls in a real-life setting, and have found that satisfaction with sound insulation and subjective ratings of noise in both types of buildings were rather similar.

It is crucial to collect data from real-life settings as the laboratory experiments or short-term measurements of noise level may not represent the conditions experienced by occupants. For example, the study conducted in Korea measured 24-hour-long recordings of noise levels in existing buildings [19]. The study found that structure-borne noises were more dominant in frequency of occurrence than airborne noises; however, no evidence has been found that floor and slab thickness may have an effect on acoustic quality. These findings are inconsistent with earlier studies conducted in a laboratorial environment [20].

Green Buildings and Acoustic Quality Studies

Green building performance has been the focal point of a number of studies and assessments in the course of the last decade. There is a broad literature on the subject analysing green buildings from economic, environmental and social perspectives, and studying the relationship between indoor environmental quality and its effect on productivity and health [10,21–29]. However, the focus on acoustic quality has been restrained and mainly limited to commercial and education facilities.

Only a few researchers have studied indoor environmental quality in green residential buildings. For example, Beauregard et al. [30] investigated the performance of LEED-certified homes in New England. The results from the pilot study suggested that there is a significant difference in designed and measured performance, but nevertheless home owners' satisfaction was very high in nearly all cases. Unfortunately, the study did not examine the relationship between IEQ (indoor environment quality) and occupants' satisfaction in detail.

Akom et al. [26] investigated 17 green low-income single attached family houses in Brandon, Canada. The findings showed that the majority of measured A-weighted BN levels were under 50 dB(A), with variation between 27.7 and 75.3 dB(A), recording marginally higher levels in living rooms than in bedrooms, and the analysis indicated a statistically significant difference in means of background noise levels across the different spaces. Interestingly, the feedback received from the occupants suggests that the distractions come from sources other than background noises. The analysis presents very interesting findings on green building performance; however, the study does not explore the relationship between general satisfaction and perception of IEQ or how the perceived noise levels affect occupants' satisfaction with acoustic quality.

The present study fills the research gap by examining the relationship between occupants' satisfaction and indoor environment quality, and the effect the problems experienced with noise level may have on general satisfaction and the perceived acoustic quality in LEED-certified and conventional residential buildings. Similarly to [10,30,31], for example, this study falls into the category of post-occupancy evaluation by using the subjective opinion of users in the evaluation of indoor environment and building performance.

2. Method

In the current study, a quasi-experimental methodology has been applied [32,33] in order to capture differences in opinion between occupants of green and conventional buildings. The multifamily buildings were chosen in such a way that all the relevant independent variables (such as geographical location, average apartment size and construction year) matched except for the environmental profile of a building. The goal was to include residential buildings certified according to internationally recognized environmental schemes and to compare results against a conventionally built (not certified) building.

Three condominiums, two green and one conventional, were included in the study. The green projects were awarded high performance certification–*LEED Gold*. The green and conventional residential buildings are located in the centre of the city. The green buildings are neighbouring buildings, and the distance to the conventional building is approximately 2 km. All buildings were completed between 2010 and 2011.

2.1. Data Collection

Data was collected in September and November 2013. The survey questionnaire was sent to all occupants of the selected buildings (1084 people) and addressed only to occupants who were at least 21 years old. The respondents could answer the questionnaire in paper form and send it back with the return envelope or leave responses online via an indicated link. All participants who submitted their contact details were sent a gratuity in the form of a scratchcard costing approximately €0.3. We received 429 responses, which resulted in 40 percent of the total response rate (Table 1).

Table 1. Response rate.

Number of	Green 1	Green 2	Conventional	Total
dwellings	225	240	168	633
send-out	384	396	304	1084
response	160	138	131	429
rate	42%	35%	43%	40%

All buildings are located in the centre of Stockholm, where environmental noise levels outside of the building can be considered moderate, but may vary during the day and night depending on the traffic and season. The green buildings are located close to the harbour, which is a popular choice for walks and evening gatherings particularly during summer time. The conventional building is located more centrally, very close to main city roads. All three buildings are within walking distance from each other, located in the same city area.

2.2. Survey Questionnaire

The questionnaire used in this study was based on a questionnaire developed by the authors and previously used in a research project [32]. The questionnaire included structured, closed questions, single or multiple choices. Respondents were offered the possibility of writing their comments in the spaces assigned to each question. This paper focuses mainly on responses regarding respondents' general satisfaction and perception of indoor environment quality (IEQ): thermal, acoustic, daylight and air quality; and experience of potential problems (Table 2).

2.3. The Analysis

The analysis was conducted using statistical package STATA ver. 14. The Cronbach's alpha coefficient for 12 items in scale was 0.71 and considered to be satisfactory.

We analyzed the data by applying a Kruskal–Wallis and ANOVA test to determine statistical differences between groups. We use ANOVA to test the hypothesis of equal means for different demographic groups, gender, family situation (living with children), and environmental profile of the building (green and conventional building). When used in the ANOVA test, the variables general satisfaction and perceived acoustic quality were defined as response variables.

Table 2. Variables and survey questions, answers and assigned values.

Variable	Question	Measurement
general satisfaction	How do you describe satisfaction with your apartment?	very satisfied (5) satisfied (4) neither or (3) dissatisfied (2) very dissatisfied (1)
thermal comfort	How do you perceive thermal comfort in your apartment (generally, during a whole year)?	very good (5) good (4) acceptable (3) poor (2) very poor (1)
air quality	How do you perceive air quality in your apartment?	
daylight quality	How do you perceive daylight quality in your apartment?	
acoustic quality	How do you perceive acoustic quality in your apartment?	
airborne noise	Have you experienced problems with noise from neighbours in your apartment (e.g., music, voices)?	never (1) sometimes (2) often (3)
ventilation noise level	Have you experienced problems with noise from the ventilation system in your apartment?	
cooking fumes (own cooking)	Have you experienced problems with cooking fumes spreading in your apartment when you cook?	
neighbours' cooking fumes	Have you experienced problems with neighbours' cooking fumes spreading in your apartment?	
temperature control	Have you experienced problems in controlling the temperature in your apartment?	
dry air	Have you experienced problems with dry air in your apartment?	

For the purpose of this paper, an ordinary logistic model was fitted to the data, testing the relationship between general satisfaction and perceived IEQ (model 1); the model (model 2) was built to test the effect of problems experienced with outdoor noise, airborne noise and noise caused by the ventilation system on satisfaction with the acoustic environment in the apartment.

Statistical significance was defined at $p < 0.05$.

2.4. Limitations

The focus of this paper is to study subjective ranking of IEQ and its relationship to general satisfaction. The limitation of this paper is the lack of on-site measurements that could provide a more comprehensive description of the environment and allow us to explore the relationship between measured noise level and occupants' subjective ratings.

3. Results

3.1. Respondents' Demographics

The number of female and male respondents was generally equally distributed (Table 3). Approximately 40% of the respondents living in the green-certified building indicated that they were living with their children, which compares with 16% in the conventional building (conventional). The majority of people living in the green-certified buildings (*green 1* and *green 2*) indicated that there were only two permanent occupants per dwelling, and in the case of the conventional building, three people per dwelling.

The analysis indicates that occupants living in the green-certified buildings are younger, the majority being in the range 31–40 years old. In the conventional building, the demography is older, one-third being more than 61 years old. The difference in age groups between green and conventional buildings is statistically significant (the Kruskal–Wallis test, the probability for chi-squared with tiles is 0.04), but we have not found a statistical significance in age groups between buildings *green 1* and *green 2*.

Table 3. Gender distribution, average number of occupants per dwelling and percentage of occupants living with children.

Respondents' Description	Green 1	Green 2	Conventional	Total
gender				
male	51%	51%	44%	49%
female	49%	49%	56%	51%
age				
20 < age < 30 years	10%	10%	8%	9%
31 < age< 40 years	34%	32%	18%	28%
41 < age < 50 years	13%	11%	19%	14%
51 < age < 60 years	15%	23%	24%	20%
61 < age < 65 years	18%	12%	15%	15%
65 years < age	10%	12%	16%	13%
occupants living with children				
with children	39%	34%	16%	31%
average number of occupants per dwelling				
mean value	2.5	2.4	2.2	2.4

3.2. General Satisfaction and Perceived Indoor Environment Quality

Results show very high general satisfaction among occupants (mean value of 4.73; Table 4), although occupants living in the green building indicate a slightly higher satisfaction level; the difference is statistically significant (probability for chi-squared Kruskal–Wallis test with tiles 0.0006). The majority of occupants have indicated that they were very satisfied with the acoustic quality in their apartments; in fact, 91% of all occupants were very satisfied or satisfied (Table 5) with the acoustic quality. The occupants of *green 1* indicated the lowest satisfaction with acoustic quality (mean value of 4.41, Table 4), the difference being statistically significant (probability for chi-squared Kruskal–Wallis test with tiles 0.044).

Table 4. Mean values for general satisfaction among occupants of conventional and green building apartments.

Variables	All Apartments	All Green Apartment	Conventional Apartments	Green 1	Green 2
general satisfaction	4.73	4.79	4.60	4.78	4.80
acoustic quality	4.48	4.43	4.59	4.41	4.46
daylight quality	4.45	4.43	4.52	4.43	4.42
air quality	4.10	4.13	4.03	4.23	4.01
thermal comfort	4.00	4.03	3.95	4.05	4.00

Table 5. Distribution of satisfaction level: general satisfaction with apartment and satisfaction with IEQ (thermal comfort, acoustic quality, daylight quality and air quality).

Occupants' Satisfaction	Thermal Comfort	Acoustic Quality	Daylight Quality	Air Quality
very poor	3%	1%	0%	2%
poor	4%	3%	1%	4%
either or	16%	5%	9%	16%
good	44%	28%	31%	40%
very good	33%	63%	58%	39%

The lowest satisfaction scores have been given to perception of thermal comfort (mean value of 4.00; Table 4), with 78% of all occupants being satisfied or very satisfied with indoor thermal conditions during the whole year.

3.3. Effect of Perceived Satisfaction with IEQ on General Satisfaction

We have tested the hypothesis of the equality of means for general satisfaction and perception of IEQ (thermal, air, acoustic and daylight comfort defined as independent variables, tested separately). The ANOVA tests were found significant, and therefore we reject the null hypothesis of equality of means (Table 6). The analysis suggests a significant relationship between IEQ factors and general satisfaction.

Table 6. ANOVA test for difference in means for general satisfaction and perception of indoor environmental quality.

ANOVA and Kruskal-Wallis Test	Air Quality	Acoustic Quality	Daylight Quality	Thermal Comfort
Kruskal–Wallis	0.0001	0.0005	0.0130	0.0001
ANOVA R2	0.1187	0.0307	0.0185	0.1043
p (model)	0.0000	0.0021	0.0206	0.0000
N	416	415	412	416
mean values per group				
very poor	4.11	4.20	4.00	4.58
poor	4.26	4.41	4.40	4.68
either or	4.58	4.75	4.55	4.42
good	4.73	4.68	4.74	4.75
very good	4.87	4.78	4.76	4.89

Since the answers are ordered categories, a statistical ordinary logistic model was fitted to data to examine the effect that perception of IEQ may have on general satisfaction (model 1a, Table 7). The computed Brant test of parallel regression assumption was 0.054, being not significant at the 0.05 level and therefore complying with the parallel assumption.

Table 7. Model 1a, ordinary logistic model describing the relationship between general satisfaction and perceived IEQ, N = 406; pseudo R-squared = 0.115.

Model 1a	(Odds)	Std. Error	p (Probability)	CI	
air quality	1.80	0.26	0.000	1.34	2.40
acoustic quality	1.23	0.17	0.141	0.93	1.62
daylight quality	1.37	0.22	0.048	1.00	1.87
thermal comfort	1.44	0.19	0.006	1.11	1.88

The results indicate that satisfaction with air quality has the strongest effect on general satisfaction (with 1.80 odds ratio); general satisfaction will increase with increase of satisfaction with air quality.

The results suggest that satisfaction with sound quality has no significant effect on general satisfaction. The reason for this result might be that the compelling majority of occupants indicated satisfaction with acoustic quality; hence, the dataset has low variation in responses.

In order to examine the relationship between general satisfaction and building environmental profile, we have introduced the binary variable *green* to the model (Table 8, model 1b) and found that the environmental profile of the building has a significant effect on general satisfaction (odds ratio 2.95 that the general satisfaction increases for green buildings, Table 8). The analysis indicates that the general satisfaction is not affected by categories other than the environmental profile of the building, since we have found the variables demographic groups, gender and family situation (living with children) to be not significant.

Table 8. Model 1b, ordinary logistic model describing relationship between general satisfaction and perceived IEQ and environmental profile of building, *N* = 387; pseudo R-squared = 0.1862.

Model 1b	(Odds)	Std. Error	*p* (Probability)	CI	
air quality	1.94	0.31	0.000	1.39	2.63
acoustic quality	1.26	0.19	0.123	0.93	1.69
daylight quality	1.52	0.26	0.017	1.07	2.14
thermal comfort	1.57	0.22	0.002	1.18	2.08
green	2.93	0.84	0.000	1.66	5.15
gable dwelling	1.05	0.09	0.530	0.89	1.25
top floor	0.66	0.21	0.206	0.35	1.26
over ground floor	0.90	0.43	0.870	0.35	2.32
ground floor	0.46	0.47	0.483	0.06	3.47
age	0.91	0.08	0.268	0.75	1.08
number people per dwelling	0.98	0.14	0.899	0.72	1.32
gender	0.66	0.17	0.129	0.39	1.13

3.4. Perception of Experienced Problems with Indoor Environment

We have asked occupants if they have experienced certain problems in apartments and to indicate the perceived frequency of experienced problems. The results show that cooking fumes which spread in the apartment are the most frequently experienced problem (mean value of 1.94, Table 9). Nearly one fourth of the respondents indicated that they often experience this problem. Spreading of cooking fumes in the apartment was found to be particularly problematic in conventional buildings (mean value 2.16).

Table 9. Mean values for perceived frequency of experienced problems with IEQ, applied scale: 1 = no problem (never experienced), 2 = sometimes, 3 = often.

Experienced Problems	All Apartments	All Green Apartment	Conventional Apartments	Green 1	Green 2
cooking fumes	1.94	1.84	2.16	1.75	1.94
controlling indoor temperature	1.79	1.81	1.73	1.94	1.88
outdoor noise	1.71	1.72	1.67	1.77	1.67
dry air	1.50	1.52	1.47	1.50	1.55
noise related to ventilation	1.39	1.44	1.27	1.59	1.28
neighbours' cooking fumes	1.28	1.30	1.23	1.23	1.38
airborne noise (neighbours)	1.24	1.25	1.23	1.22	1.29

Results suggest that occupants relatively often experience problems with difficulty in controlling indoor temperature and level of outdoor noise (mean values 1.79 and 1.71, respectively). The majority of occupants have not encountered problems with noise caused by neighbours (76%) or noise related to the ventilation system (66%, Table 10). The results suggest that occupants in *green 1* experience problems with noisy ventilation relatively more often than occupants in other buildings (mean value being 1.59 in *green 1*, 1.28 in green building 2 and 1.27 in conventional building), the difference being statistically significant (probability for chi-squared Kruskal–Wallis test with tiles 0.0001).

Table 10. Distribution of perceived frequency of experiencing problems with IEQ.

Experienced Problems	No Problem	Sometimes	Often
outdoor noise	40%	54%	6%
airborne noise (neighbours' noise)	76%	23%	1%
problems with noise caused by ventilation system	66%	29%	5%
problems with cooking fumes	29%	48%	23%
problems with controlling indoor temperature	39%	44%	18%
dry air	59%	31%	10%
problems with cooking fumes (neighbours)	74%	23%	3%

It would be very interesting to examine the cause of this difference; however, it can only be determined by inspection and close investigation of the ventilation system and connected apartments, which is outside the scope of this study. The occupants of *green 1* indicated the highest perceived frequency of disturbance from outdoor noise (mean value 1.77, Table 9); the difference was found to be not statistically significant.

3.5. Effect of Experienced Problems on Satisfaction with Acoustic Quality

In order to investigate whether the experienced problems have an effect on satisfaction with sound quality in the apartments, we have performed an ANOVA test and fitted data to the ordered logistic model 2.

A test of equality of means for satisfaction with noise quality has been performed and the results (Table 11) show that satisfaction with noise quality decreases with perceived frequency of experiencing a problem. It is interesting that mean values for quality of acoustic environment are significantly lower for the group of occupants who often experienced problems with a noisy ventilation system and who often encounter noise from neighbours than those who often experience outdoor noise. This would suggest that the effect of experiencing problems with noise from neighbours has the greatest effect on subjective acoustic quality.

Table 11. ANOVA test for difference in means of satisfaction with acoustic quality and perceived frequency of experienced problems.

ANOVA and Kruskal-Wallis Test	Outdoor Noise	Airborne Noise	Noise Caused by Ventilation System
Kruskal–Wallis	0.0001	0.0001	0.0001
ANOVA R2	0.0734	0.1701	0.0642
p (model)	0.0000	0.0000	0.0000
N	419	419	415
mean values per group			
never	4.76	4.67	4.63
sometimes	4.33	3.87	4.26
often	4.17	3.75	3.95

We put forward the hypothesis that occurrence of indoor noise (caused by neighbours or ventilation) has greater impact on satisfaction with sound quality than frequently experienced outdoor noise. The analysis confirms our expectations (Table 12) and shows that experiencing noise from neighbours (0.19 odds ratio that satisfaction will increase if the problem occurs) has the strongest negative effect on satisfaction with acoustic quality.

Table 12. Model 2a, ordinary logistic model describing relationship between satisfaction of indoor acoustic quality and perceived frequency of experienced problems; *N* = 412, pseudo R-squared = 0.12.

Model 2a	(Odds)	Std. Error	*p* (Probability)	CI	
airborne noise	0.19	0.04	0.000	0.12	0.31
outdoor noise	0.44	0.07	0.000	0.31	0.62
noise caused by ventilation system	0.54	0.09	0.001	0.38	0.77

We have used a Kruskal–Wallis and an ANOVA test to examine whether satisfaction with sound quality differs within groups of the following categories: environmental profile (green building), number of occupants per dwelling, occupants living with children, age and gender of respondents and location of dwellings in the building. The analysis showed a significant relationship only for environmental profile (chi-squared with tiles $p = 0.019$). The ordinary logistic model (model 2b, Table 13) showed no significance for any of the categories.

Table 13. Model 2b, ordinary logistic model describing relationship between satisfaction of indoor acoustic quality and perceived frequency of experienced problems; *N* = 393, pseudo R-squared = 0.0.138.

Model 2b	(Odds)	Std. Error	*p* (Probability)	CI	
outdoor noise	0.43	0.08	0.000	0.30	0.63
airborne noise	0.19	0.04	0.000	0.11	0.31
noise caused by ventilation system	0.59	0.11	0.005	0.40	0.85
green	0.62	0.16	0.077	0.37	1.05
gable dwelling	0.92	0.06	0.316	0.80	1.07
top floor	0.72	0.20	0.260	0.41	1.26
over ground floor	0.49	0.20	0.089	0.21	1.11
ground floor	0.28	0.26	0.180	0.04	1.78
age	0.89	0.07	0.187	0.75	1.05
number people per dwelling	0.95	0.16	0.770	0.67	1.34
gender	0.97	0.22	0.929	0.62	1.53

4. Concluding Comments

This paper has contributed to the literature on acoustic quality by investigating the effect that problems experienced with noise level may have on subjective rating by analysing the effect of these problems on general satisfaction and the perceived acoustic quality. Additionally, we have investigated whether a difference in perception of acoustic quality exists between an environmentally certified and a conventional residential building.

The results show that occupants are very satisfied with their apartments and subjectively rated acoustic quality received very high scores. These findings are in line with previous studies conducted in Sweden [33,34]. We could only partially confirm the relationship between general satisfaction and IEQ, as the analysis has found acoustic quality not to be statistically significant. This is in line with an earlier study comparing newly built, green and conventional buildings in Sweden [33], which found acoustic quality not to be significant. However, Zalejska-Jonsson and Wilhelmsson [34], who examined IEQ in sampled apartments in Sweden, showed that the acoustic quality has a significant effect on general satisfaction, finding that perception is related to construction year and geographical location. The difference in findings might be associated with improvement in building insulation, choice of material and strengthening of building regulations. This study has focused on newly constructed buildings only (similarly to [33]), whereas research presented by Zalejska-Jonsson and Wilhelmsson [34] was not limited by building production year, in fact, nearly half of the responses came from occupants living in buildings constructed before 1960.

The results show that experiencing noise from neighbours occurred relatively seldom; however, this factor has the strongest effect on satisfaction with acoustic quality. The most frequently experienced problem was outdoor noise level; however, the analysis suggests that the effect on subjectively perceived acoustic quality is rather low. This is an interesting finding, and being in line with the findings of Gozalo et al. [17] it demonstrates that occupants are prone to distinguish and find most unpleasant sounds that are sharp and loud. The literature has indicated that outdoor noise, even frequently experienced, can in certain respects be controlled by closing windows [19]. In the year we conducted the survey, Sweden experienced a heat wave during the summer period. In order to control indoor temperature, a common strategy is to open windows and create a cross-draught. Since the studied buildings are located close to areas popular during the summer, it is possible that the perception of outdoor noise was intensified during that time.

We have found that the environmental profile of a building has a significant effect on the general satisfaction expressed by its occupants; however, this effect has not been confirmed for acoustic quality. The analysis indicates that occupants in one of the green buildings found the ventilation system more distracting than other occupants, and this might be an explanation for the marginally lower ratings for acoustic quality in that building.

Funding: This research was funded by the Swedish Energy Agency grant number 37518-1.

Acknowledgments: In this section you can acknowledge any support given which is not covered by the author contribution or funding sections. This may include administrative and technical support, or donations in kind (e.g., materials used for experiments).

Conflicts of Interest: The author declares no conflict of interest.

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