Indoor Annual Sunlight Opportunity in Domestic Dwellings: What is the Relationship with Well-being in Urban Residents in Scotland?

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Abstract

Indoor sunlight improves health in hospitals, schools and workplaces, and there is clinical evidence for the impact on depression, but there is a lack of evidence for a positive impact of sunlight in domestic dwellings on residents' health and well-being. This could have important implications for building design and resident's indoor behavior, and impacts on health. Using a cross-sectional survey we investigated the relationship between annual indoor sunlight opportunity and psychological well-being in 40 residents of high-rise dwellings in a socio-economically deprived area in Glasgow, Scotland.

Perceived physical health, physical activity, psychological distress and indoor environmental factors were considered as mediators of the relationship between annual sunlight opportunity and well-being. We used novel simulation modeling of window size, orientation, occlusion and occupant behavior to measure annual sunlight opportunity.

We found a significant positive association between well-being and annual indoor sunlight opportunity, but not between sunlight and objective indoor environmental variables such as air quality, bacteria and fungi. Perceived physical health, lower psychological distress, more physical activity and better perceived environmental quality were associated with greater psychological well-being. Perceived physical health was the only variable which mediated the impact of sunlight on well-being. Findings merit replication in larger and more heterogeneous samples but have implications for building design and advice to residents on window occlusion.

213 words

Keywords: Architecture and Design; Environmental Psychology; Positive Psychology.

Introduction

This study investigates the relationship between sunlight and psychological well-being in domestic dwellings in Scotland, a northern European country. Solar radiation depends on latitude and regional climatic differences – Glasgow has 15% less sunlight than Copenhagen at similar latitude (Page & Lebens, 1986) and a maritime climate. Sunlight has a positive aesthetic and psychological effect, and may also affect physical health. We suggest increasing sunlight access to homes, particularly in areas with limited sunlight, could enhance health and well-being, improving living environments.

Psychological Well-being

Psychological distress, depression, and low mood are relatively frequent problems, particularly in people in the lowest socio-economic quartile in Scotland (Scottish Health Survey 2011). Improving happiness, or psychological well-being is complex, reflecting not merely reducing distress, but promoting the experience of positive affect. Recent studies in 'positive psychology' identify two main approaches to understanding 'well-being' (Ryan & Deci 2001). The hedemonic focuses on happiness, expression of pleasure or positive emotion, and longer-term life satisfaction or 'subjective well-being' (Diener 1984). The eudaimonic approach has an existential focus on 'good' or meaningful life, personal growth and self-actualisation (Ryff 1989). It is unclear how sunlight affects hedonic and eudaimonic well-being. Aesthetics and longer-term impacts may relate to hedemonic qualities. Studies identify positive links between sunshine and psychological functioningincluding improved mood and better cognitive functioning (Howarth & Hoffman 1984; Watson, 2000; Kent , McClure, Crosson, Arnett, Wadley & Sathiakumar, 2009) even when participants spent most of their time indoors

(Kööts, Realo & Allik, 2011). The blue visible range (450-495 nanometres), commensurate with 75-85% transmission through double-glazing (Johnson, 1991) promotes affective arousal and improved mnemonic processing (Vandewalle, Schwartz, Grandjean, Wuillaume, Balteau, DeGueldre et al, 2010, and associations between bright light and improved vigilance have been observed (Vandewalle, Maquet & Dijk, 2009; Beute & de Kort, 2014) in some but not all studies (Dennisen, Butalid, Penke & van Aken, 2008; Huibers, de Graaf, Peeters & Arntz 2010; Lucas & Lawless 2013). One route may be via the impact on serotonin levels, which influence depression (Lambert, Reid, Kaye, Jennings & Esler, 2002). In clinical populations light therapy is an effective treatment for low mood including Seasonal Affective Disorder (SAD), and natural daylight appears more effective than artificial light (Wirz-Justice, Graw, Kräuchi, Sarrafzadeh, English, Arendt al, 1996). However, clinical studies may not extrapolate to general population samples. Effect sizes involving the impact of daylight and sunlight are small (Golden, Gayes, Eckstrom, Hamer et al 2005; Even, Schroder, Friedman & Rouillon 2008). Scottish population studies evaluating the relationship between mood and sunlight found a small effect on negative affect (Dennisen et al., 2008) and positive associations between window size and positive mood in the home (Fung, 2008b), suggesting passive solar features may improve air quality, keeping humidity and CO_2 low.

Mechanisms for the Effect of Sunlight on Health

Physical Health

There is evidence for a positive relationship between sunlight exposure and health. Possible mechanisms are UVB exposure and vitamin D synthesis outside buildings, improving immune functioning and reducing fatigue (Beute & de Kort, 2013).

Early research suggested direct sunlight is more powerful than daylight as a germ-killing agent, and daylight more powerful than artificial light in suppressing streptococcal and respiratory tract infections (Buchbinder, Soloway & Phelps, 1941; Soloway, Solotorovski & Buchbinder 1942) . However, the advent of antibiotics diverted attention from health benefits of sunlight in buildings. With growing concerns about antibiotic resistance and indoor air quality there is renewed interest in daylight and sunlight in buildings and its impact on health (Beute & de Kort, 2014).

Psychological well-being and physical health are mediated by biological factors (Dennisen et al., 2008; Steptoe, Dockray & Wardle, 2009) and health behaviors such as physical activity (Tucker & Gilliland 2007). Other mediators include socio-demographic variables (e.g. socio-economic status), and personality (e.g. optimism).

Sunlight in buildings

There is a positive relationship between sunlight in public buildings and health and well-being, including enhanced health recovery from depression (Beauchemin & Hays 1996; Kent et al. 2009), heart attack (Beauchemin & Hays 1998) and in post-operative care (Walch, Rabin, Day, Williams, Choi, & Kang, 2005). Window size, position and sunlight penetration impact positively on mood and satisfaction of sedentary office workers (Boubekri, Hull & Boyer, 1991). However, these reviews generally exclude domestic dwellings (Edwards & Torcellini, 2002). This is unfortunate, as many people spend most of their time indoors, particularly those with young children or confined to home because of illness or disability. Studies report mothers with young children spending 18.4 hrs/day inside the home in England, (Farrow, Taylor & Golding, 1997) and 16.6 hrs/day inside for women and 14.7 for men in Germany (Brasch & Bischof, 2005).

Older people show a significant drop in outdoor activity or walking after age 75 (Dallasso, Morgan, Bassey, Ebrahim, Fentem & Arie 1988).

Architects have emphasised benefits of daylight and sunlight within buildings for health and hygiene (Overy, 2007). Recently, drives for energy efficiency including lower ceiling heights and smaller windows (as with German PassivHaus standards) reduce the amount of sunlight entering domestic dwellings, reducing opportunity for sunlight exposure and improved air quality (Fung, 2008a). There is a need to investigate the issue of domestic fenestration in relation to well-being (Kaplan 2001). Existing studies mainly focus on perceptions of sunlight (Bitter & van Ierland, 1965) or emphasise external views (Markus & Gray, 1973; Tennessen & Cimprich, 1995) .

Whilst short-term exposure to sunlight may affect day to day mood, it is important to evaluate longer-term opportunity for sunlight to examine its impact on health and subjective well-being. We aimed to investigate links between sunlight opportunity in domestic dwellings and psychological well-being using validated psychological measures, and to develop a reliable measure of indoor sunlight.

Hypotheses:

1. There will be a positive direct effect of indoor sunlight opportunity on physical health, mediated by indoor environmental factors (dust, fungi, bacteria and air quality).
2. There will be a positive association between indoor sunlight opportunity and psychological well-being.
3. The direct effect of indoor sunlight opportunity on psychological well-being may be mediated by physical, psychological, behavioural and environmental factors.

Methods

Study design

This was a cross-sectional observational study, involving face-to-face interview surveys of residents of high-rise tower blocks in Glasgow, Scotland in their domestic dwellings and environmental survey of their main living rooms.

Domestic Dwellings

A housing association which provides rental accommodation allowed us to recruit residents. We aimed to control for confounding factors. Using a cluster of four identical tower blocks in close proximity with different aspects allowed us to control dwelling (flat) size, type, layout (2 variants), window size, type of glazing (the same in each dwelling) and orientation (varying for each of 6 flats per floor). Views in the immediate vicinity for all dwellings included areas of green landscaping with stands of trees to the north, east, south and west. The nearest corners were over 30 metres apart and all views are open and embrace both sunlight and shade. We balanced orientation (20 flats with main living room windows facing south, and 20 north), however we were able to recruit 20 south, 13 north and 7 east/west facing. Floor height may affect shading and view, but there were only 2 dwellings below floor level 3. Median level was floor 12, maximum was 22 storeys. The housing stock (constructed 1971) was newly re-furbished so interior finishes were of similar quality. The socio-economic profile of residents was homogeneous, and mainly economically or socially disadvantaged.

Participants

Participants were resident in the tower blocks and surveyed at a time of year to ensure potential access to sunlight for at least 9 daylight hours (British Summer Time, October 2011). Participants (n=40) were recruited by 4 researchers during daylight hours. We included adults (18+), who spoke English. To improve participation all residents were sent a letter indicating that researchers would be contacting residents door-to-door during a set time period, giving contact details allowing residents to opt-out in advance or be contacted later. The local housing office and the concierges were informed about the project and promotional posters were displayed. If the occupant was absent, a leaflet with contact details was left. Surveyors obtained signed consent before data collection, making a maximum of 2 additional attempts to contact residents. Researchers carried photographic ID and mobile phones, working in pairs for security. Participation was confidential. All data was anonymised. An incentive of £20 shopping vouchers was awarded when air quality monitoring equipment was retrieved.

A structured interview and environmental survey was carried out in each dwelling. One occupant per household was interviewed by a researcher. Concurrently, a second researcher carried out an objective appraisal of the dwelling recording data to enable calculation of sunlight opportunity in the main living rooms, physical dimensions of daytime living spaces (living room and kitchen), and installed monitoring equipment to record temperature, humidity and air quality (CO_2 measurement) over a defined period (minimum of 24 hours). The interview/ installation and environmental data collection lasted no more than one hour. Data on daily sunlight hours during the data collection periods was retrieved from the UK Met Office (http://www.metoffice.gov.uk) to account for potential short-term mood-related responses.

A sample size of 40 was identified as sufficient for this exploratory feasibility study due to cost and time limitations. This enabled us to estimate numbers needed to show a significant effect of sunshine on the main outcome variable (well-being), with reasonable precision and calculate effect sizes for future work. Ethical approval for the study was granted in advance by Ethics Committees of two participating institutions.

Participant Measures

Psychological Measures

We measured positive and negative factors, since both influence health.

Psychological Well-being: The Warwick-Edinburgh Mental Well-being Scale (WEMWBS) (Tennent, Hiller, Fishwick, Platt, Joseph, Weich et al., 2007) is a 14-item scale of mental well-being covering hedonic subjective well-being and psychological functioning. Items are worded positively and address aspects of positive mental health, e.g. 'I've been feeling good about myself'. Items are answered on a 1 to 5 Likert scale (possible range 14-70) and summed. The WEMWBS has been validated for use in the UK with those aged 16 and above. It showed good internal reliability (Cronbach's α =.94).

Psychological distress was measured using the General Health Questionnaire -12 (GHQ) (Goldberg & Williams, 1988). It has twelve questions, assessing general affect, depressive and anxiety symptoms and sleep disturbance over the last four weeks. Interpretation is based on a four point response scale scored using a bimodal method (symptom present: 'not at all' = 0, 'same as usual' = 0, 'more than usual' = 1 and 'much more than usual' = 1. A cut-off of 3 indicates psychological distress requiring therapeutic intervention. Cronbach's α was .86. Both WEMWBS and GHQ measures were used in the most recent (2011) Scottish Health Survey, providing comparative data.

Physical Health

Perceived physical health was rated by one item as used in the Scottish Health Survey

(2011), 'How would you rate your health in general over the past few weeks?, scored 1 (very bad) to 5 (very good).

Long-term physical health. We rated presence of a long-term physical or mental condition or disability (duration at least 12 months, rated yes/no), and if yes, to specify.

Health behavior

Several health behaviors may affect the relationship between indoor sunlight and well-being. We hypothesised that physical activity would be an important mediator, by improving fitness and potential exposure to outdoor sunlight. We asked about frequency of moderately strenuous physical activity (e.g. brisk walking) over the past 3 months, rated as 1 (never) to 6 (every day). Smoking was also investigated, rated 'yes' or 'no', and if yes, number of cigarettes, cigars or pipes smoked per day.

Subjective Environmental Measures

Subjective environmental quality : 9 variables rated perceived overall environment quality, using semantic differential scales rated 1 to 7 (stale/fresh; dreary/bright; cluttered/spacious; uncomfortable/comfortable; stuffy/airy; dark/bright; irritating/calming; dry/damp; cold/hot). We deliberately avoided leading questions on perception of sunlight. A total subjective environmental quality score (possible range 9-63) was calculated. This measure showed good internal consistency (Cronbach's α =.85). As a check, researchers were asked to rate the overall environmental quality using the same scale as participants (Cronbach's α = .72).

Demographics: We used demographic categories from the Scottish Health Survey (2011), including; *Age group* (scored 1-9, categories from under 21 to over 90); *Marital status*: never married or registered same/sex relationship, married, civil partnership, cohabiting, separated but still married/in civil partnership, divorced/dissolved civil partnership, widowed/ surviving partner from civil partnership; *Occupancy*: who participants lived with and if they had pets; *Socio-economic status* was assessed via highest education level (0=none, 1 = standard grades/O level, 2 = Scottish 'highers'/A levels, 3=Scotvec/NVQ (vocational qualifications), 4 = degree/postgraduate qualification; *Current employment status* - 11 categories including: employed > 16 hours/week, employed < 16 hours, self-employed, unemployed, full-time carer, looking after family/home, retired, student, temporary sick, long-term sick (Scottish Health Survey, 2011).

Objective Environmental Measures

Dust, fungi and bacteriological samples from the living room carpet were collected, vacuuming selected areas for 30 seconds. House dust mite antigen was extracted from dust. Levels of bacteria and fungi were determined by weighing a portion of the dust and preparing a dilution series. The plates were incubated and total number of colonies per plate determined. Monitoring equipment was installed in the living room to record *Indoor Air Quality (IAQ).* Parameters recorded were temperature (T °C), relative humidity (RH %) and carbon dioxide levels (CO_2, ppm) over a minimum of 24 hours.

All equipment was small and non-invasive and installed and collected by the researchers within 48 hours. A pilot trial was conducted where researchers were observed to ensure correct deployment and operation of equipment.

Annual Sunlight Opportunity

We created a theoretical 'annual sunlight opportunity' metric to calculate potential in the main living room, modelled over an annual duration, rather than what was received at the time of the surveys (i.e. to map sunlight onto the windows and through them onto horizontal and vertical surfaces). The method reflects the changing sun's altitude and azimuth angle from sunrise to sunset, based on theoretical 'clear sky' throughout. This was preferable to using actual recorded hours of weather dependent sunlight, subject to the randomness of cloud cover and precipitation, (see 3.2 below). Orientation and window size was determined from building plans. Photographic recording of windows assessed over-shading and occlusion by curtains and blinds. Illuminance was measured at the window centre (directly to the outside) and in the centre of each room to provide an objective indicator of brightness. To accurately define the value of the 'opportunity' we identified contributory metrics, using a unit of square meter hours per annum (m^2h/y) - area of sunlit surface multiplied by the time involved in exposure per annum.

1.Sunlight aperture opportunity (SAO) - sunshine falling on the external glazed surface of an aperture (window) computed in hourly steps from sunrise to sunset over a theoretical 'clear sky' day, including self-shading due to orientation and plan configuration of the towers as well as their over-shading.

2*. Sunlight surface opportunity (SSO)* -sunshine passing through windows to living rooms and falling on internal surfaces, computed as for SAO.

To assess self-reported participant behavior participants estimated *Room Occupancy:* Hours spent in the main living room in the previous day, and on average over the last 2 weeks; and *Window occlusion:* how often curtains/blinds were drawn, on a 4 point scale (never - always). Derivation of the metric was achieved through digital modelling and simulation using the 'SunCast' programme. This modeled at hourly steps for a day in the middle of each month, extrapolated for a full year. Analysis of the first simulation of all 40 flats, without taking account of occlusion due to blinds or curtains, showed neither SAO nor SSO directly correlated with well-being. Subsequent interim simulations concentrated on two 'focus' flats with opposite orientations (living room main windows facing north or south, small windows east or west); firstly assuming 50% occlusion and then varying from 20% to 80% in 20% increments. The time period of assessment was limited to between 09.00 and 18.00 hours to capture the most likely period of actual sunlight opportunity. This 'snapshot' was then applied for all 40 dwellings. Technical details are available on request.

Analysis

Relationships between variables were examined using Spearman correlations (reflecting non-normal data and small sample sizes). We investigated the relationship between annual sunlight opportunity, psychological well-being, and potential mediating variables (general health, psychological distress, physical activity, environmental quality) to determine associations and effect sizes. Mediation was investigated using regression analysis and bootstrapping techniques accounting for small sample sizes (Preacher & Hayes 2004). This non-parametric approach does not require a specific sample size, although reliability increases with sample size. Indirect effects were investigated using Bias corrected estimates (BCa) of confidence intervals at 95% with 1000 bootstrap samples. In linear regression analysis mediation effects are significant if the upper and lower bounds of the confidence intervals do not contain zero.

Results

Demographic information

We interviewed 40 participants, mean age group 4.1 (age 41-50) (SD1.3, range 2-6 (21-30 to 61-70)). Most (n=25, 62.5%) lived alone, 9 (22.5% lived with one other), 5 (12.5%) with a child and 9 (22.5%) had a pet. Few (5, 12.5%) had higher educational qualifications, 16 (40%) had highers/A levels/vocational qualification and 17 (42.5%) had no qualifications/standard grade/O levels. A few (7, 17.5%) were employed part-time, 16 (40%) were unemployed, 8 (20%) were on long-term sick-leave and others were retired (7, 17.5%), students or on short-term sick-leave. Sex, race and immigration status was investigated but revealed no heterogeneity, so is not reported here. Mean duration of residence was 98 months (SD 73), indicating a relatively stable population. Mean self-reported living room occupancy on the previous day was 6.9 (SD 4.0) hours, which highly correlated with the estimated average of 6.6 (SD 4.4) hours over the past 2 weeks (r=.67, p=.0001). There was no relationship between employment status and perceived environmental quality, general health, well-being or psychological distress.

Daily Sunlight

Mean daily hours of sunlight for Glasgow over the interview period (October 4th – 28th 2011) was 2.8 (SD 3.2) (range 0-9.2). There was an inverse relationship between mean hours of sunlight (UK Met Office data) and annual sunlight opportunity (r_s = -.48, p=.008) based on uniform 'clear sky' conditions. This may be partly due to including participant behaviour (window occlusion, room occupancy). Window occlusion (blinds, curtains) was negatively related to well-being (r_s=-.30, p=.058). Correlations relating hours of sunshine on the day of interview to environmental variables (including window occlusion or room occupancy), psychological well-being and physical health showed no significant associations.

Orientation

Living room orientation was: n=13 (33%) north, 20 (50%) south, 5 (12.5%) east and 2 (5%) west. There was a significant relationship between orientation (living room window) and annual surface sunlight opportunity – south and west facing dwellings had significantly more sunlight opportunity than others ($F(3,30) = 4.69$, $p=0.008$, $\eta^2=.32$). There was no difference in psychological well-being by orientation of dwellings.

Indoor Environment

Table 1 shows values for Indoor Air Quality (IAQ) and other monitoring variables, and their association with annual sunlight opportunity**.** House dust mite levels were very low, with valid samples collected from only 4 dwellings. Environmental conditions were generally comfortable. Mean maximum temperature (21°C) is in the recognised comfort temperature range (19-23 °C) and relative humidity level (54.29%) sits within a broad comfort range (Chartered Institute of Building Surveyors Institute, 2006). CO_2 mean concentration was below the maximum desirable level of 1000ppm suggesting air quality was generally reasonable. Airborne fungal and bacterial counts indicate the dwellings monitored were typical of clean dry houses. More than 50% of the fungal and bacterial counts were in the very low category (Commission of European Communities, 1993). Correlations with sunlight opportunity are in the expected direction for carpet fungi and bacteria, but not for other variables. Annual sunlight opportunity unexpectedly correlated positively with higher CO_2 and humidity.

Physical Health

Mean subjective ratings of health over the past few weeks was 'fair' (mean 3.2, SD 1.3). Many participants (27, 67.5%) had a long term physical or mental health condition or disability; 10 (25%) reported a current mental health condition and 20, (50%) a physical health condition. Most frequently reported problems were asthma, arthritis, diabetes and depression. In relation to *Hypothesis 1*, the correlation between annual indoor sunlight opportunity and self-rated health was non-significant (r_s =.28, see Table 2) and there was no relationship between self-rated health and objective environmental observations in Table 1. There was no difference in annual sunlight opportunity, or in psychological well-being or distress for those with or without long-term health conditions.

Psychological Well-being.

WEMWBS mean score of 49.1 (SD 12.18) in this study is below the Scottish population mean of 49.9 (Scottish Health Survey 2011) although not statistically significant (one sample t-test) [95%CI -4.7, 3.10].

Psychological distress, measured using the GHQ (mean 2.95, SD 3.16) was relatively high, 30% scoring above a cut-off of 3.00 indicating anxiety or depression requiring therapeutic intervention.

Health Behavior

Physical activity was relatively frequent (mean 4.1, SD2.0; representing 2-3 times per week). There were no differences between smokers (n=16, 40%) and non-smokers (n=24, 60%) in well-being or distress. However, for smokers, those with less annual sunlight opportunity smoked more (r_s = -.43). Mean cigarettes smoked per day was 17.6 (SD 9.3) (range 3-40 per day).

Subjective Environmental Quality Ratings

Mean subjective environmental quality ratings were 43.9 (SD7.1) and 40.0 (SD5.5) for participants and researchers respectively, and moderately inter-correlated (r_s=.56, p=.001). There was no relationship between residents' perceived environmental quality and environmental conditions (IAQ, bacteria, fungi), or window orientation.

For *Hypothesis 2,* we examined the relationship between annual sunlight opportunity and psychological well-being (Table 2), which was positive and significant. Table 2 includes data for potential mediators; perceived physical health, psychological distress, physical activity, and subjective environmental quality. Although not significantly related to sunlight opportunity, these variables all significantly correlated with psychological well-being.

Regression models predicting psychological wellbeing

Using simple linear regression analysis, annual sunlight opportunity was a marginally significant predictor of well-being (model r^2 = .09; F(1,38)= 3.57, p=.06) . Mediation is sometimes not considered where the relationship between the predictor and dependent variable is non-significant (Baron & Kenny, 1986), however a mediation effect may still be evident (Hayes 2009), which is relevant for further work. For *Hypothesis 3*, we tested mediators of the relationship between annual sunlight opportunity and well-being, using separate regression models with annual sunlight opportunity entered first, using bootstrapping techniques to estimate indirect effects (Preacher & Hayes, 2004) (Table 3). Perceived physical health (Model 1) was a significant mediator, whereby the BCa 95%CI for B became non-significant at the second step. There was no significant change in BCa 95%CI for physical activity, psychological distress or environmental quality suggesting no mediation effect.

Conclusions

This was a novel study quantifying long-term impact of sunlight in domestic dwellings on health and well-being, using valid and reliable measurement of environmental and psychological variables. We developed a robust methodology gathering data for architectural form and construction, environmental conditions, bacteriological sampling and psychological well-being. Complex modelling allowed us to estimate long-term annual exposure to sunlight, and we found a significant effect of sunlight opportunity on psychological well-being. Further analysis tentatively suggested this was mediated by physical health. This is important, since we know there is a direct relationship between psychological well-being and physical health (Steptoe et al 2009). Our study also found well-being was positively associated with more physical activity, less psychological distress and better environmental quality. This is an unsurprising finding, but merits further investigation in a larger, more detailed study to understand the role of sunlight in promoting health, and the relationship between 'indoor' and 'outdoor' environments and behaviours.

It is important not to overestimate these effects. There were many confounding factors, and we acknowledge this was small-scale, exploratory research. Nevertheless, findings offer important directions for future work with implications for promoting psychological well-being.   The study was also under-powered. Post-hoc power analysis using G*Power for ES $r = .31$, $\alpha = .05$, power .80, suggested a minimum sample size of 79. , indicating effects may have reached statistical significance in a larger sample. Future work should study larger, healthy populations and increased heterogeneity of dwellings, including objective measures of physical health. More detailed analysis using biometric markers such as vitamin D or immune factors would help to clarify mechanisms.

We cannot determine causality using this methodology. People with more well-being may be more predisposed to maximising their exposure to sunlight, both indoors and outdoors. People may also prefer less sunlight when unwell or depressed, or may watch more television if confined indoors, where windows may be occluded for longer periods of time. More detailed measurement of actual indoor sunlight exposure would be useful.

There is generally only a modest correlation (Cloninger 1986) between trait and short term 'state' or mood measures of wellbeing. We did not measure mood as our interest was in long-term effects. The study was carried out in Scotland, where overall annual sunshine hours are among the lowest in Europe, so findings may vary in other locations, and the impact of sunlight may be negative. Future work could examine seasonal longitudinal effects, residents' occupancy behaviour and window use, and sunlight appreciation. It is also important to capture subtleties of the impact of sunlight on psychological well-being. We used only one measure focusing on hedemonic and mental health aspects of well-being. Other eudaimonic aspects such as personal growth and spirituality (Ryff 1989) may be enhanced by exposure to sunlight, aesthetically pleasant living environments and external views (Kaplan, 2001). In-depth analysis of mediating factors of the relationship between sunlight opportunity and well-being, including relevant health behaviors, physiological markers, physical health outcomes, and social support is warranted, as well as more detailed measure of participants' use of outdoor spaces, and outdoor sunlight exposure.

Internal housing environments are important determinants of health inequalities (Gibson, Petticrew, Bambra, Sowden, Wright, & Whitehead, 2011). Overall quality of environment in the sampled housing (recently refurbished) was very good. Bacteriological levels were low, temperature, air quality were satisfactory, with positive perceptions of environmental quality. We could not find an 'antibiotic' effect of sunlight on moulds and bacteria, perhaps due to existing low levels in these dwellings. However our population was characterised by high levels of physical and mental morbidity. The impact of sunlight may be dwarfed in such a population with long-term conditions, facing substantial health challenges. Nevertheless, the profile of these residents is typical of this type of dwelling in inner-city urban areas, and it may be doubly important for these groups to be exposed to the benefits of sunlight for their physical and mental health.

In housing there are many confounding factors and we controlled as many of these as possible (construction, flat size and type, daytime occupancy etc.) There are many other potential confounders, including people's beliefs about the benefits or otherwise of sunlight, open, closed or occluded windows which could be explored in qualitative work. Since housing dominates the building environment and human experience, potential to maximise exposure to indoor sunlight is important. Our metric is now being evaluated in on-going building performance studies across the UK and will inform building, urban design and interior environmental design, providing advice for occupants about benefits of sunlight exposure and encouraging better design of domestic housing to promote well-being.

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Table 1: Correlations between Indoor Environmental Conditions and Annual Sunlight Opportunity

Parameter	**N**	**Mean (SD)**	**Min/max**	**Correlation with SO (Spearman R)**
Annual sunlight opportunity (m^2h/y)	34	1510.0 (1259.6)	153/4392.3	-
[a]Temperature (°C)	36	20.5 (1.8)	14.6/24.8	-.30
[a]Relative humidity (%)	36	54.29 (8.5)	39.3/69.0	.39*
[a]CO_2 Concentration (ppm)	36	875.01 (322.0	448.7/1776.9	.42*
Fungi	40	76.1 (75.7)	10/365	-.07
Bacteria	40	789.8 (854.2)	70/4105	-.07
Carpet Fungi	27	69.3 (71.9)	.70/295.4	-.15
Carpet Bacteria	33	134.7 (176.2)	1.7/583.1	-.23

[a] Rows 2, 3 and 4 give the mean maxima over a 24-hour period

**p<0.05; **p<0.01: ***p<0.001*

Table 2: Spearman Correlations showing the Association between Well-being, Annual sunlight opportunity and potential mediators.

		Mean (SD)	1	2	3	4	5	6
1	Well-being	49.10 (12.18)	-					
2	Annual sunlight opportunity	1510.0 (1259.6)	.36*	-				
3	Perceived physical health	2.95 (3.16)	.49**	.28	-			
4	Physical activity	4.10 (2.04)	.39*	.05	.60***	-		
5	Psychological distress	2.86 (14.9)	-.74***	-.19	-.27	-.22	-	
6	Environmental quality	43.92 (7.14)	.44**	-.01	.23	.08	-.34*	-

**p<0.05; **p<0.01: ***p<0.001*

Table 3: Simple Linear Regressions testing mediation of the Relationship between Annual sunlight opportunity and Well-being.

Model, Step		B (SE)	Beta	t (p)	[b]BCa 95% CI	
					Lower	Upper
Model 1 Perceived Physical Health						
Step 1[a]	Annual sunlight opportunity	.003 (.002)	.30	1.90#	.001	.006
Step 2	Annual sunlight opportunity	.002 (.002)	.15	1.01	-.001	.004
	Perceived physical Health	5.04 (1.70)	.44	2.97 **	.59	8.32
Model 2 Physical Activity						
Step 2	Annual sunlight opportunity	.002 (.001)	.24	1.70	.000	.005
	Physical Activity	2.77 (.83)	.46	3.33 **	1.18	4.41
Model 3 Psychological Distress						
Step 2	Annual sunlight opportunity	.002 (.001)	.17	1.46	.000	.004
	Psychological distress	-2.6 (.44)	-.68	-5.87***	-3.55	-1.80
Model 4 Environmental Quality						

Step 2	Annual sunlight Opportunity	.003 (.002)	.29	1.99	.001	.005
	Environmental Quality	.67 (.25)	.38	2.65*	.19	1.35

Final Model 1 Perceived Physical Health: Adjusted R sq = .22 F(1,37) = 8.83 **

Final Model 2 Physical Activity: Adjusted R sq = .26 F(1,37) = 11.01**

Final Model 3 Psychological Distress: Adjusted R sq = .50 F(1,37) = 34.48***

Final Model 4 Environmental Quality: Adjusted R sq = .19 F(1,37) = 7.00*

[a]*Step 1 is common to all four models*

[b]*BCa: Bias corrected accelerated confidence intervals*

 # p=.066

**p<0.05; **p<0.01: ***p<0.001*