Samuels, R. (1999), Light, Mood and Performance at School: Final Report

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Executive Summary (Phase#1, 1998)

An Interim Report to DET/DPWS (Feb 1999) described and evaluated the field research carried out in 1998 (before and after full spectrum lamps were installed in 8 experimental classrooms). Major findings indicated that after installation of the full spectrum lights anxiety, depression and S.A.D. syndromes (lethargy etc) improved, or occurred significantly less. Furthermore, inattention also decreased and was related to improved behaviour. There also seemed to be a strong relationship between S.A.D. and inattention.

These findings seem to afford some measure of empirical evidence confirming the theoretical expectations based on the literature review of overseas studies: that full spectrum light improves mood and attentiveness in school children.

Executive Summary (Phase#2, 1999)

The second phase of the research emerged fortuitously, overcoming difficulties experienced during Phase#1 where interactions with the teachers were inevitable, and possibly deleterious to the validity of the results. The Phase#2 research method was able to avoid this issue completely. Results indicate a *very highly significant influence of full spectrum light* on virtually every aspect evaluated (in 34 of the 35 items on the assessment scale). The Psycho-Biological assessment instrument/scale itself also proved to be highly reliable, with a high measuresof internal consistency. A range of statistical procedures were applied to verify the findings - with consistently positive outcomes. It is now feasible to assert that the full spectrum lighting conditions have made a substantially positive difference to the attentiveness, mood, state of mind and behaviour of the students *ie* to their generic performance at school.

This research is unique in the sense that it is the first to assess full spectrum lighting and mood and performance at school using a psycho-biological assessment scale; and, generally, it is the first work of its kind in Australia.

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1 INTRODUCTION

The motivation for undertaking the research reported here is the need to know, from the DPWS/DET point of view, whether or not a change towards a full spectrum lighting (FSL) regime in schools in New South Wales might be educationally justified. Copious northern hemisphere research suggests beneficial results from FSL; albeit putting theory into practice in the real world inevitably throws up innumerable complications and interpretations about what is precisely happening in the photobiological interaction of humans in their environment.

The research question posed here is whether a country like Australia, blessed with sunlight, is comparable to northern European ‘winter-countries’ where daylight shortens significantly, and seasonal affective disorder syndromes (S.A.D. or 'winter blues') become more prevalent, inducing depression and influencing performance. The aim, thus, is to evaluate the extent to which full spectrum fluorescent lighting in schools affects student mood and performance - in Australian conditions.

The researcher has previously reported to the EFRG concerning the theoretical impact of light, in schools in particular, on mood, arousal/attention and performance.[1] The current empirical research relies on *teacher assessment of student performance*; and a special assessment tool was developed for this purpose, the composite Psycho-Biological Assessment Scale (PBAS) - a schedule of 35 items relating to student mood, attentiveness and behaviour. It appears robust since its statistical reliability is very high, and the results reported here are thus robust in that sense (see 4.3).

Several potential constraints, borne of the reality of undertaking field research were reported in the Interim Report; and the value of a minimalist approach reiterated (consciously altering only one variable: the lighting).

[1] see: Samuels and Stephens (1996): Colour and Light in Schools

In effect, two separate studies were conducted in the same field setting, in 1998 and 1999 respectively, employing a variant experimental approach. Results from the first study were generally positive; results from the second were highly significant - both were in the theoretically expected direction. Together these findings should be considered robust, and indicative of the positive affect of full spectrum lighting - even in Sydney, Australia conditions.

Rationale for undertaking the study

Humans are photo-chemical organisms, light/dark adapted, with inbuilt bio-chemical switches tuned to these rhythms. The master gland in this *arousal/attention and quiescence/inattention oscillation* is the pineal, secreting melatonin and responding to daylight in a complex photon-neuron interrelationship. Humans have evolved in the presence of natural daylight and sunlight for millennia, yet in the past half-century have come to spend the majority of daylight hours inside buildings which are artificially lit. As society becomes more urbanised, this is exacerbated. School students spend considerable amounts of time indoors, in spectrally deficient fluorescent lighting conditions – especially during the winter months, when natural light levels are relatively low, even in Sydney. This could be deleterious to their photobiological balance and performance. Even where daylight enters the building this could be the case, since after transmission through glass the light is no longer equivalent to natural daylight - it is 'attenuated'. To the degree that glazing absorbs or reflects daylight the pineal-light response could be affected.

Although this ‘interior illumination’ spectrum is depleted in comparison to natural light, technology now allows us to artificially *simulate daylight.* To this end, daylight-simulating or full spectrum artificial lighting was installed in eight classrooms, while in four the standard cool-white fluorescents were retained, as the basic research methodology.

2 GENERAL THEORETICAL CONSIDERATIONS

2.1 Neuro-Endocrine and 'Photo-Somatic' Interactions with Light

Fundamental to the research undertaken here is the recognition of the neuro-endocrine response of humans to the environment. This is a 'psycho-somatic' response where any interaction with the environment – physical, social or emotional - prompts an associated internal chemical interaction between the brain and the neuro-endocrine glands (hypothamalus, pituitary, adrenals…), whether the stimulus is experienced as negative or positive. Stress responses (and their consequences, for instance: cortico-steriod and adrenalin secretions) are well recognised (see Samuels, 1978 for review). Less well recognised is the *non-visual* response to light *ie* where light acts as a potent form of energy, having profound impacts on well-being both physical and psychological, and thus potentially on mood, arousal, attention and performance. Again, the hypothalamus is intimately involved in this 'photon-neuron' response. It is connected via a separate nerve pathway to the retina, from which impulses travel to the suprachiasmatic nuclei which serve as a vital component of the internal biological clock, timing the 24^{hr} (circadian) cycles of physiology, behaviour and biochemistry.

Furthermore, the *photo-sensitive* neuro-endocrine *pineal* gland is associated with light/dark cycles, and secretes the hormone melatonin in the dark, which conditions arousal and sleep. Where people are exposed to light, either natural or, if artificial, daylight-simulating/full spectrum, melatonin secretion is properly managed. Where light levels are low or the visual spectrum is attentuated (after passing through glazing, for example) or incomplete (as in standard fluorescent lighting), melatonin continues to be secreted (unnaturally).

Standard levels of standard indoor lighting (400 to 500 lux) are thus said to be equivalent to 'biological darkness' – Lewy *et al* (1980), Brainard *et al* (1988). Full spectrum artificial lighting, on the other hand, includes not only the visible spectrum in daylight proportions[2] but also 'near' ultra-violet (UVA) and seems

[2] "Vitalites (Duro-Test) contain UV radiation in approximately the same proportion to visible light as that found in natural daylight" (Hathaway, 1995, citing manufacturer information)

able to simulate the effect of natural light, even at standard illumination levels, *over a period of time.*

Further evidence of the salience of light to human well-being derives from the manifest success of *light-therapy* in people suffering seasonal affective disorder symptoms, particularly prevalent in the winter months, particularly in the northern hemisphere - which mood-state is now known to be associated with light deprivation. Positive responses to regular exposure to bright, full spectrum light bears witness to the reality of light as bio-energy (Lewy *et al*, 1980, Rosenthal *et al*, 1984, Brainard *et al*, 1990).

Lighting engineers and architects typically use as their measure *levels* of lighting which are adequate for vision (or to create ‘atmosphere’) but not for psycho-biological stimulation. Moreover, energy efficiency pursuits frequently result in either lower levels of illumination or the use of lighting which is far from daylight-simulating (sodium lamps, for instance). The consequence of either or both can manifest as depression of the nervous system, low arousal, emotional depression, lethargy and headache; and/or the so-called ‘winter-blues’ or ‘S.A.D’ syndrome. Further important consequences are a drop in attentiveness, or an increase in distraction or inattentiveness. [See Samuels *et al,* 1996 for review]. A depressed mood-state, coupled with a state of low arousal, an ill-balanced biological clock and disharmonious psycho-somatic functioning, not surprisingly, is likely to result in a fall-off in performance.

2.2 Natural Daylight and Attenuated Indoor Light

Humans are biologically attuned to natural daylight. It contains all colours (all wavelengths in the visual spectrum) in relatively uniform amounts – no sharp peaks or discontinuities in the spectral distribution (Hathaway, 1995). Technically, daylight is rated as having a Colour Rendering Index or CRI of 100; and lamps which simulate daylight to levels of CRI 95+ are currently termed full spectrum. The extent to which people are deprived of FSL is the issue at stake here. Although daylight inside buildings is preferred to artificial lighting (Collins, 1975; *inter alia*) and plays a vital energy efficiency role, it is not biologically balanced light. Indoor daylight is *attenuated ie* <u>not</u> full spectrum, since glass does not transmit the full spectrum of daylight. Even 3mm, single-pane clear glass permits only 86% visible spectrum and 78% UV transmittance; while with low-E insulated glazing these levels drop to about 55% and 30%, respectively. 13mm bronze plate glass, frequently used on high rise office towers, transmits only 25% of the visual spectrum (Johnson, 1984; Germer, 1985; ASHRAE, 1989).

Clarke (1979) showed these transmittance differences occurring in the red and *particularly in the blue* extremes of the spectrum, and called the result: interior daylight, or ID_{65} (6500K being the 'correlated colour temperature' of daylight). Kok et al (1985) confirmed this by measuring the spectral irradiance inside a room, and recording higher UV concentrations when the windows were open. Both glass and building materials absorb UV wavelengths. The importance of this realisation is that indoor daylight will not have the full psycho-biological benefits of outdoor daylight. Daylight simulating artificial lighting has a vital role to play, in this regard. It is, nonetheless, true that whatever daylight enters a building is biologically and psychologically beneficial for the people inside. At worst there might be some experience of glare, particularly where the sky is visible (skylight is very bright), yet these conditions can usually be simply neutralised by appropriate shading or screening. And daylight is diffuse; it is not sunlight, where thermal discomfort or reflections on white paper or computer screens might prove dissatisfactory. Indeed, although the inevitable variability of the daylight exposure of respondents in all research on both daylight and daylight-simulation seems rarely to be appreciated, the fact is that virtually all studies indicate positive affects of enhancing interior daylight (to whatever degree attenuated).

The extent to which these affects could be enhanced by a fuller comprehension of the role of glass and other materials in absorbing spectral energy would seem to be research for the future. Very recent 1999 research (personal communication with Lisa Heschong: see 3.3 Daylight and Productivity) on daylight and performance in a huge sample of school children (over 2000 classrooms) took note of 'tints' – the heavier the tint the less the transmission of visible light assumed. A light tint (allowing 40-60% transmittance of visible light) reduced their window/daylight rating by one notch on a 5 point rating scale, and a heavy tint (10-30%) by 2 notches. Performance improvements of over 20% were recorded in reading and maths where the internal daylight was greater. One further and intriguingly significant finding might well be a vital clue to the indoor daylight attenuation issue. In classrooms where windows *could be opened* students were also found to progress 7-8% faster. Controlling for this variable is unattainable during field research under normal school conditions (how often were the windows opened, what where the atmospheric conditions at the time, which students were closest to the window, are the blinds drawn, in which orientations are the windows?). Although previous research (synthesised in Samuels, 1986) indicates that having control over environmental conditions such as lighting, heating and ventilation – thus openable windows - is highly appreciated by personnel, and is beneficial to performance, it is teachers who would have control over opening windows and not students who would make these decisions, in this case. The positive affects in student performance should thus be attributed to the penetration of an enhanced quality of the light.

2.3 UltraViolet Radiation (UVR)

The wavelengths of daylight making up UVR span from 400_{nm} to 100_{nm} and miniscule quantities are produced by all fluorescent lamps. Indeed, it is ultraviolet radiation that activates the phosphors coating the inside of fluorescent tubes (5 different phosphors in FSL) – and is responsible for the fluorescence and the eventual emission of light. The very thin glass sheath of the fluorescent lamps themselves and especially the plexiglass/plastic diffusers absorb almost all the shorter wavelength UVR emitted, while UVA (315 to 400_{nm}) is largely transmitted, at least through the clear glass of the lamps (Thorington, 1967 and 1985; Ott, 1982; Ronchi & Bodmann, 1984; Cole *et al*, 1985).

In the field of photo-biology, UVA or ‘blacklight’ is the photon range demonstrated empirically to be beneficial, indeed considered necessary and natural for human functioning. UVA would appear to constitute what might be called the *benign* quanta of ‘actinic’ light *or* the ‘biologically-activating’ spectral zones. There is also an important threshold point of relevance here. As the UV wavelengths get shorter, through UVB to UVC, the impact on humans is more radical, from triggering the UVB/Vitamin D response in the skin (Neer, 1985) to the more bacterial, germicidal and ultimately carcinogenic affects of UVC exposure. In this regard, as early as 1981 the Australian Commonwealth Department of Science and Technology evaluated Artificial Light at Work and declared UVA ‘harmless to the eyes'.

Full spectrum daylight-simulating artificial light is designed to emit ‘trace’ amounts of UVA, even micro-traces of UVB, and substantial amounts of blue-violet light. These are its most distinguishing characteristics in comparison to other artificial light. From studies undertaken by the following researchers: Birren, Zamkova, Krivitskaya, Volkova, Sharon, Neer, Thorington, Wurtman, Kuller, Erikson, Wetterberg, Kuller, Wolfarth and Hathaway…the positive impacts of UVR exposure encompass immunological, enzymatic and anti-bacterial resistance to disease, enhanced calcium absorption, decreased melatonin and cortisol secretion…as well as increased academic performance and reduced visual fatigue.

With regard to visual performance it is cogent to note, from yet another perspective, that the spectral power distribution of daylight simulating FSL is important where the level of light begins to fall (affecting pupil size and thus depth of field – or the so-called scotopic sensitivity of the eyes). Scotopically-enriched light has been associated with better performance on challenging visual performance tasks, and while daylight simulating fluorescent light has a scotopic/photopic ratio of 2.22 (similar to sunlight @2.28), the standard cool-white lamp ratio is only 1.46 (Berman 1992, 1993, 1994).

Hathaway's (1995) research with school children 'enhanced' UV exposure by the simple strategy of using aluminum egg-crate diffusers, thus, in fact, by blocking less and reflecting more. In the research reported here, some debate over this issue ensued, but the luminaires installed at the Seven Hills West school could not be fitted with egg-crate diffusers. To avoid any potential source of concern about exposure of school children to more UVR (in UV-conscious Australia) it was deemed prudent to leave the plastic diffusers as they were normally deployed, albeit disallowing any 'enhancement' effects.

2.4 Duration and Intensity of Light

There appears to be a fundamental dichotomy in the research undertaken on full spectrum lighting. The great majority of researchers seem to appreciate the reality of the 'photon-neuron' relationship, and design their studies to span considerable periods of time before expecting a response to light - for instance: Ott (1982), Hughes (1983); Erikson and Kuller (1983); Rosenthal *et al* (1984); Wurtman 1985; Wohlfarth (1986), Lindsten and Kuller (1987), Samuels and Ballinger (1992). Lindsten and Kuller's work with school children was over a one-year period, Wohlfarth's over a 10-month period, Ott's over a two-month period; while Erikson and Kuller's office research was conducted over a 6-month period, and Samuels and Ballinger's over an 8-month period. This understanding recognises that exposure over several months, at normal illuminance (400-500 lux), allows this ephemeral energy source the time to modify bio-chemical and psycho-somatic functions. Even exposure to very bright light (2500+ lux) requires several hours to get a sustained response. Lewy *et al* (1980) reported that melatonin concentrations begin to diminish after about 20 minutes of exposure @2500 lux, and reached daytime levels after about an hour; but @500 lux exposure there were no noticeable differences in concentration levels during those periods.

However, some more recent research seems to neglect this vital element. These studies bring subjects into an artificial environment for brief periods of time (Boray *et al*, 1989; Veitch *et al*, 1991; Baron *et al,* 1992). Boray and colleagues report, for instance, that after 35 minutes no significant differences were found among three lighting types (warm-white, cool-white and full spectrum); Veitch and colleagues exposed their respondents to test conditions for 45 minutes, during which time they undertook separate tasks lasting 2, 5 and 15 minutes – with no distinguishing response. In this study respondents were *told to expect* either better *or* worse performance under FSL lamps, and produced better performance in both cases. The researchers did mention the 'short exposure time', but this did not affect their evaluation of the validity of their results; and although sophisticated statistical analyses were undertaken the basic premise remains flawed.

Baron *et al* (1992) found no effects of luminous conditions on mood and performance. The exposure time for subjects was not stated, but can be inferred from the description of the tasks set to be about 20-40 minutes. Knez (1995), who criticises this work on this dimension himself fails to state the duration of his own experiment – although he does reports some positive findings relating to cognitive performance via enhanced mood.

It should not be expected that low levels of indoor light for brief periods of time should influence diurnal patterns of melatonin secretion or suppression. This fundamental breach in understanding and thus research procedure is both surprising and alarming, since spurious inferences are made as a consequence (such as recommendations to <u>not</u> install FSL).

> In the research reported here the first cohort of students (phase#1) were exposed to the FSL conditions from after Easter until the end of October, some 6 months; the phase#2 cohort from the end of January to the end of June, some 5 months.

2.5 Efficiency and FSL

Studies show that higher quality light is *perceived* as being equivalent to poorer quality light at higher levels of illumination. The Westpac study (Samuels and Ballinger, 1992) similarly showed that high quality full spectrum lamps were perceived as being more satisfactory on several visual dimensions than lamps of lower quality but higher illuminance. This suggests that full spectrum lamps, relatively inefficient as they are, can be employed efficiently by using less lamps per area (and by supplementing the luminaires with reflectors). Moreover, Vitalite™ the internationally best known full spectrum lamp company, now produces a lamp which emits 25% more light than older models, again enhancing the possibility of intelligent energy management resulting in energy consumption savings (www#2).

2.5 Lamp Characteristics

The rationale for the choice of the experimental lamps to use in the research reported here has been previously described (Samuels, 1998: *Interim Report*). Suffice it to repeat, here, that the Vitalites and Ottlites, the world leaders in FSL, are both very expensive imports in comparison to lamps readily available in Australia (manufactured by Philips and Osram/Siemens, amongst others). In the event that the research indicated a positive relationship between performance at school and FSL, it would have been unreasonable to recommend that the DET/DPWS consider their deployment – given the costs associated with expensive imports. On the other hand, the seemingly efficacious FSL Osram Lumilux de Luxe–Daylight™ lamps employed in the preceding Westpac research are readily available, at a higher cost than standard issue, naturally, but not prohibitively. These lamps were consequently and eventually opted for in the research.

Their light characteristics are the following:-

* 8 Experimental Classrooms
  - ♦ **Lumilux de Luxe–Daylight L36W/12 - 950**
    CRI[3] = 95 and CCT[4] = 5400K

* 4 Control Classrooms

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[3]CRI = Colour Rendering Index (100 = perfect daylight-simulation)
[4]CCT = Correlated Colour Temperature (>5000=cool)

- **Standard Education Dept. Issue 'Cool-White' Fluorescent lamps**
  CRI = 65 and CCT = ±4000K

It also proved daunting to cross compare various lamps; either information is withheld (commercial-in-confidence?) or different measurement scales are employed. According to documentation from Osram/Siemens, the UVA and UVB potency in the Siemens FSL-12 series used in this research employed in the research is 50mW/m^2 (45 and 5, respectively), while in a standard example of the cool-white type total UVR is only 0.16 (according to Sylvania Lighting documentation).

3 FULL SPECTRUM LIGHTING STUDIES: PRECEDENTS

Over 30 years of research into the relationships between mood, attention and performance and the spectral quality of light has shown that exposure to FSL inside buildings results in fewer vision problems, less fatigue, enhanced alertness, improved performance, less lethargy, and diminished hyperactivity; while in spectrally unbalanced artificial light and in the absence of daylight lethargy and cortisol secretion (a stress hormone) increase, visual acuity drops, dissatisfaction increases, and so on.[5]

Virtually all studies that have been carried out regarding the relationship of light (whatever its source) to performance are, however, equivocal and indeterminate to some degree - given the large number of other intervening variables which also have an impact on performance, such as neuronal and metabolic proclivities, past experience, or motivation, *inter alia*. Inevitably, visibility is implicated – virtually all tasks in all walks of life include a visual component which is central to their function. Yet, *non-visual* as well as visual variables are also part of this same equation. This multi-dimensional aspect makes it difficult to draw conclusions about the influence of light on performance.

[5] see Samuels *et al*, (1996) for a full review.

3.1 School Studies

In order to briefly describe the theoretical and empirical context in which this present study has been undertaken, a chronological synopsis of studies **relating specifically to schools** (and other students), as well as some other studies with salient findings, follows:-

Harmon's 1942 research was the precursor of later studies using full spectrum lamps. He showed that the health of school children was impaired when they were exposed for *long periods* of time to artificial light with a lack of ‘brightness’ due to its reduced spectrum.

Maas *et al* (1974) explored the relationship between spectral differences in environmental illumination and both objective fatigue (a decrement in performance, measured via the Critical Flicker Fusion test) and perceptual fatigue (feelings of weariness for instance, as measured by bi-polar semantic differential tests) in university students. Cool-whites and Vita-lite (FSL) fluorescents were the test lamps used. The subjective variable: *lively-lethargic* proved to be significant. Subjects under the cool-white light tended to become less lively and more lethargic, while there appeared to be no changes under the Vita-lites, which were also found to enhance visual acuity (subjects could see more clearly).

Hughes (1980, 1981) researched the effects of full spectrum lights on school children, and reported increased visual acuity, reduced overall fatigue, improved work performance, and lower rates of illness due to colds. Such findings apparently led to the specification of full spectrum lighting for schools and workplaces in the ex-USSR. In such conditions, children apparently grow faster, their work ability and grades improve and catarrhal infections are fewer (Birren, 1972a).

Wohlfarth and Sams (1981) conducted research using full spectrum lighting *and* shades of blue in classrooms; and reported drops in systolic blood pressure for both sighted and blind children. Sydoriak (1984) replicated this study and found significant reductions in both systolic and diastolic blood pressure in blue classrooms. Wohlfarth and Sams also reported a large drop in aggressive and non-attentive behaviour; and that teachers felt more relaxed, reporting more work completed.

John Ott (1982) reported on a number of studies undertaken in the mid-70's relating to fluorescent lighting and the behaviour of children at school. He conducted a study at a school using full spectrum, radiation shielded lamps, during a two-month period. Hyperactive children calmed down, learning disabilities decreased, and academic level increased in children exposed to the daylight-simulating lamps. A photographic record shows the progression of a distracted and hyperactive boy, initially unable to sit still, moving closer to the teacher, and finally at the blackboard taking part in the regular classroom activities. A time-lapse film is available from the International Film Bureau, Chicago showing hyperactive children calming-down in classrooms equipped with full spectrum lamps. Ott further reported on two studies undertaken by Californian schools which confirmed this relationship (p.130-133); and also mentions a School Board which had voted unanimously to remove the high pressure, sodium vapour lights that had been installed, in the interest of energy efficiency, in about a dozen schools. This was after many complaints by teachers and students listing such problems as headaches, eyestrain, nervous tension and nausea.

Ingraham (1983) examined the effects of electromagnetic radiation - emitted by the ballasts of all fluorescent lamps - on ‘off-task’ or hyperactive behaviour, using classrooms with cool white/*un*shielded lamps, full spectrum/*un*shielded lamps and full spectrum/*shielded* lamps. Significant differences occurred in the latter situation, where observers noted decreases in inattentive, disruptive, and inappropriate behaviours. Mayron and Ott *et al* (1977) had previously found similar improvements in hyperactivity in school children with full spectrum radiation shielded lamps. Electronic ballasts improve energy efficiency remarkably, but are expensive to purchase; shielding also incurs further costs.

In 1986 Wohlfarth extended his earlier work, undertaking the most comprehensive school field experiment to date, testing performance in classrooms with yellow in students' vision and blue in teachers' vision, together with full spectrum lighting. This extensive study involved four elementary schools, grades 1 to 6, over a 10 month period.

The Control school had standard lighting and so-called traditional wall colours in off-white to brown shades, and brown carpets; one of the three experimental classrooms was equipped with FSL-only (traditional colours); a second had only 'psychodynamic' colours *ie* walls painted cool-blue (predominantly in teachers' vision) and yellow (a warm colour) in students' vision, with blue chalkboards and brown carpets; and the third had both FSL and blue-yellow. Further experimental classroom situations involved altering ultraviolet and radiation levels.

Inevitably, a range of confounding extraneous parameters influenced outcomes. The researcher isolates the blending of cool and warm colours in the same room as a 'fault' in the experimental design (because of confounding field-of-vision effects). Further constraints would have included the amount of time spent outdoors, window opening, extent and quality of indoor natural daylight, even overshadowing. Such factors are extraordinarily difficult to control, and are present as constraints on interpretation in all photo-biological research, whether mentioned or not.

Although, overall, insights from the Wohlfarth study are inconclusive, some significant changes were evident in *mood states*. Sadness, aggression, 'surgency' or cheerfulness, and self-mastery and self-esteem were evaluated via the Pre-Adolescent Mood State test (PAMS).[6] Scores for self-mastery/esteem

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[6] elements of which were included in the PBAS teacher assessment schedule used in the

were significantly and consistently *lower* in both the Control and the psychodynamic colour-only classrooms. The researcher considered this to be a robust finding indicative of beneficial effects in both the FSL light-only and the FSL/blue-yellow conditions, in which students had greater feelings of surgency and self-esteem. Further, Control students scored significantly higher on aggression. Noise levels were also measured in the libraries of the architecturally identical Control and FSL/blue-yellow schools, with significantly less noise measured in the latter (5-6 dBA quieter).

In an extension to the research, two classrooms were fitted with full spectrum/ultraviolet supplemented lighting, permitting UV radiation in the mid and near UV range; while two others had conventional lighting. Significantly lower levels of dental caries were recorded over a 22-month period in the FSL/UV classrooms. Further, in comparison to a FSL-only classroom there was significantly less absenteeism in the FSL/UV conditions.

Zamkova and Krivitskaya (1966) had earlier noted school children reacting positively to ultraviolet erythrine lamps in USSR school research. Wohlfarth also cites 6 further studies where ultraviolet light had beneficial effects on school children, the elderly, factory workers, and animals.

Lindsten and Kuller (in Kuller, 1987) studied about 100 school children, aged 8-9, for one year. Again, experimental and Control lamps were used. Children in the classroom which had neither natural daylight (no windows at all) nor simulated daylight had significantly higher cortisol secretion levels during winter.

The Alberta Dept. of Education supports work by Canadian researchers on the effects of FSL and UV on school performance, and prominent work is emerging from them as a result. In a recent two-year study with elementary students, Hathaway (1995) developed Wolfarth's earlier work; showing reading and mathematical ability improvements (similar to Heschong's findings on daylight

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research reported here

in schools cited later), as well as reduced dental caries and absenteeism, in FSL/UV↑[7] conditions. The worst results were evident in the high pressure sodium vapour lighting conditions. Overall, in the FSL conditions there was significantly better attendance than in the cool-white conditions; and greatest achievement gains in language and math were in the FSL conditions, UV supplemented or not.

As in all other photo-biological research, there is no mention of the impossibility of controlling for the confounding influence of natural daylight exposure of each student. Although initially attempted in the research reported here a resolution was not found, due to the complexity of extracting this information from students themselves. Similarly, all prior research has not made any mention of issues relating to interior daylight, attenuated after passing through glass.

3.2 Relevant Findings from Other Studies

Disturbances in the endocrine functioning of people as a result of exposure to spectrally unbalanced and intense artificial light were reported by Hollwich and Dieckhues (1968, 1972). As the intensity of the light increased, cortisol secretions increased.

Following on this work, Hollwich *et al* (1975) related low spectral quality lighting to fatigue, while Hofling (1973) had found a relationship with headache episodes.

Greiter *et al* (1979) documented how natural or simulated sunlight had a positive effect on physical working capacity, decreasing heart rate and increasing oxygen uptake.

Hollwich and Dieckhues (1980) undertook further research regarding the influence of two sources of strong artificial illumination (3,500lux) - one a

[7] UV enhancement of 4-6 times was achieved by using aluminium egg-crate diffusers

cool-white, the other a daylight-simulating lamp. They found stress-like levels of the hormones ACTH and cortisol in the group exposed to the cool-white lamps for a fortnight, but this effect was absent in the daylight-simulating group. The researchers suggested that these differences explained the agitated mental and physical behaviour and fatigue of students under artificial illumination with a strong spectral deviation from sunlight, as reported by Maas *et al*, in 1974.

Hughes and Neer (1981) reported on a large number of studies linking Vitamin D synthesis to ultraviolet radiation and documenting its deficiency in indoor workers working under artificial light with little or no UVR below 315_{nm}. Some years earlier, Neer *et al* (1971) had exposed a group of veterans to cool-white lighting, and found their intestinal absorption of calcium declined during winter periods.

Hughes (1983) reported further on a number of studies he undertook to determine the psychological impact of simulated natural light and cool-white light. Office workers evaluated their work environment, their work task and their feelings as a function of lighting type. The results supported the conclusion that the daylight-simulating light was perceived as significantly more pleasing, natural, bright and stimulating. Observers felt more relaxed, less fatigued and experienced greater eye comfort. They also rated their tasks as being more distinct, easier and satisfying.

Employing the same evaluation techniques and lamps, Hughes (1983) evaluated an indoor training facility, used by rowing crews. Significant differences were found for pleasantness, brightness, feelings of healthiness, and strong physical strength. He also evaluated whether such lighting would influence high-school wrestlers training indoors. Here he employed the Critical Flicker Fusion test too, which proved to be significantly improved under the daylight-simulating conditions, demonstrating greater activation and decreased fatigue. Again, a large array of survey items proved significant: pleasantness, naturalness, stimulation, and positive effect on strength, *inter alia*.

Erikson & Kuller (1983) compared the effects of white and daylight-simulating lamps on 55 office workers in Sweden over half-a-year. People working in the daylight-simulating lighting had fewer vision problems and reported less visual fatigue. Melatonin secretions were also reduced during the winter, and people felt more alert and active. Scores on mood scales indicated a significantly higher ‘social mood’ and ‘drive’.

Samuels & Ballinger (1992) evaluated socio-personal and energy-environment consequences of the deployment of three fluorescent lighting types, installed on different floors of an office building in Sydney (55 respondents), after an eight-month period. Light systems ranged from low spectral quality cool-whites (CRI 63, CCT 4100K), to energy-efficient, higher CRI Triphosphors (CRI 85, CCT 4000K) and daylight-simulating/ full spectrum lamps (CRI 95, CCT 5400K). From a self-report questionnaire evaluating satisfaction with lighting, and the incidence of S.A.D and SBS[8] episodes, six significantly beneficial experiences were recorded in the daylight-simulating condition. These included greater satisfaction with lighting, generally; and with the colour, level and clarity of the light. Crucially, less headaches were reported, and employees felt more energetic at work.

3.2 Daylight and Performance/Productivity

Although this is not the place to evaluate daylight and productivity, generally or specifically, it is necessary to remind ourselves that daylight is the central issue, albeit artificial daylight in the particular case-study undertaken here. Discussion of the preference of people for daylight has been previously presented to the DET/DPWS. Suffice it to say here that a literature review on the issue of Daylight and Performance/Productivity has recently been prepared for

Pilkington (Samuels, 1998[9]), where an overall, wide-spread definite improvement with daylight enhancement was noted. Also noted was the endemic difficulty of separating out the *non-light* motivational and experiential complexities involved. The review concluded that whether the beneficial effects can unequivocally be attributed to daylight *per se* or not, they are real, and there is only advantage to be gained by adding daylight to the workplace. Workers react positively to daylight both psychologically and biologically, but also seem to interpret the interest shown by management as caring, and so respond positively in any event.

Of special note are studies on supermarket chains. A fortuituous Wal-Mart example is of interest. An atrium and central skylights provided daylight to the building in question. Fortunately for our understanding of the daylight-productivity factor, the decision by the company to install only half of the skylights – as a cost-cutting measure – inadvertently revealed an impact on productivity which has a high likelihood of being due to daylighting directly. Sales per square foot were significantly higher for those departments located in the daylit half of the store compared to those without the skylights. Sales were also higher here than in the same departments in the company's other stores (Romm and Browning, 1994).

A further and most convincing recent study of daylight-workplace productivity was carried out in 108 stores of a large supermarket chain, which indicated about 40% enhanced sales where skylights had been installed compared to almost architecturally and product identical stores without skylights. This research was by the Heschong Mahone Group, for the California Board of Energy Efficiency, as reported in the Sacremento Bee, June 28th 1999.

To conclude, it is appropriate to cite the findings of the Heschong study of natural daylight and performance in *school children*. 21,000 elementary students made up the huge sample. A comparison in over 2000 classrooms in

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[8] SAD = Seasonal Affective Disorder; SBS = Sick Building Syndromes
[9] commercial-in-confidence

three school districts (with different dependent variables) showed students either 'progressed faster' on standardised tests as amount of daylight increased, or did better (higher absolute test scores). These improvements averaged out at around 20-25% in reading and 15-20% in mathematics.

The lead researcher, Lisa Heschong is cited as saying: "daylight affects us biochemically in ways that alter alertness". And Steve Selkowitz, renown head of the building technologies department of the Environment Energy Technologies Division at the Lawrence Berkeley Laboratory in California said: "while the energy conserved by daylighting makes a big difference nationwide, that's not as exciting…as its effects on the people inside (buildings)". Coming from him, this endorsement is extremely salient.

4 METHODOLOGY

4.1 Two Field Research Empirical Approaches

The empirical research model applied here developed over the several years of the Seven Hills West school investigation. Eventually, two methodological approaches were tested in the field conditions, with different teacher/student respondents: the Before/After study in 1998 (n=312) and the Control/Experimental study in 1999 (n=328). In both, teachers evaluated student mood states, attentiveness and overt behaviour via the scale specifically developed for the purpose. In both approaches an experimental intervention was involved *ie* 8 classrooms were fitted with full spectrum lighting, the only variable intentionally altered. The 4 Control rooms had standard departmental issue cool-white fluorescent lamps fitted *ie* new lamps, since fluorescents degrade over time (to compare like with like). The Control and experimental rooms were the same in both phases.

It was crucially important that teachers should not be aware of the particular lighting conditions in their classroom (students were oblivious to the experimental conditions). *Yet,* given the conflicting ethical and procedural necessity to inform them, to some degree, of the nature of the research in which they were essential participants, some mention was made of a hypothetical relationship between light and well-being at briefings during the ‘pilot’ phase and Phase#1 (as previously reported). In order to overcome these conflicting requirements it was eventually decided to mention the installation of a *range* of different lighting types in different classrooms but not how many different types would be involved nor which room would be equipped with which type.

At these briefings there was some measure of skepticism expressed by some teachers, and also some discussion aimed at debunking notions that ‘more intelligent’ classes would automatically score better (the PBAS is not aimed at measuring intelligence but mood and comportment, and light, theoretically, should impact on old and young, female and male, geniuses and idiots alike).

Phase#1 (1998) methodology involved a Before assessment (all classrooms with standard lighting) and an After assessment (after the 8 experimental classrooms were fitted with FSL, and the 4 Control rooms with new cool-white lamps). Students and teachers were assigned to particular classrooms according to the Principal’s normal requirements, and irrespective of the research being carried out. The four Control rooms were randomly selected, in the sense that they were the ones which were found, during the re-lamping period over Easter in 1998, to have old light fittings which could not accommodate the slimmer full spectrum lamps. The experimental rooms were selected by virtue of the fact that they had suffered water damage to their ceilings and were being refurbished in any event by the Department of Education. Indeed, this was the rationale for the selection of the particular school for this field experimental research in the first place. In other words, the selection of school, rooms, teachers and students was without reference to any research agenda, and can be considered random. In both phases only the teachers knew the identities of the students themselves (a coding system was employed).

It later became apparent, however, that this difficult initial research situation, which inevitably involved raising teacher consciousness, could be readily overcome if a second study was carried out the following year, in the already equipped classrooms, without mention to anyone other than the Principal. The advantage of this approach was discussed with the Departments and the Principal and deemed to warrant pursuing, in the full expectation that teachers would be satisfied with the rationale for such a strategy once de-briefed at the conclusion of the research.

This constituted the Phase#2 methodology, where teachers in the 12 classrooms were asked to assess their students only once, some 5 months after exposure to the different lighting conditions, having been *unaware of the continuing research* situation until that time. This latter condition is believed to have contributed to the exceptionally significant findings of Phase#2 - since the likelihood that 'Hawthorne' or uncontrollable motivational factors (positive or negative) might influence the course of the research was substantially reduced. Teachers and students would have experienced the situation - unselfconsciously - and only *after* the fact would it be evaluated as a research setting. This now resembles a classic post-occupancy evaluation model, where an experimental intervention and it's potentially huge impact is not present.

Again, the teachers and students in Phase#2 were assigned to classrooms according to the Principal's agenda, irrespective of any research conditions – and were thus randomly distributed. Those who happened to be assigned to the rooms which had the full spectrum lamps installed (the previous year) became the experimental group (n = 219); and even the researcher was unaware of the nature of this distribution until receipt of the completed assessment schedules at the conclusion of the research. In the event, a full range of classes were evaluated: one kindergarten class, two year-1s, two year-2s, two year-3s, two year-4s and three year-5/6s. Precisely which teachers were involved in Phase#2 is still unknown at the time of writing.

Given the magnitude of the significance emerging from the analysis, scientific skepticism is necessary, despite the multitude of tests applied to the data which suggest that this is unwarranted. The only possible way that the data could have been consciously manipulated by the assessors (and it is surely an affront to their integrity to even suggest such a possibility) is that they knew which lights were in which rooms, correctly determined the difference in their spectral parameters, comprehended the theoretical implications of the photon-neuron response, and had the common intention to skew their responses. It is true that the full spectrum lights are somewhat bluer than the standard cool-white issue. Besides the fact that there are windows on both sides of every classroom allowing diffusing daylight to enter, the plastic diffusers have been left in place as usual, and the rooms themselves are a plethora of colours. Even if some of the same teachers were involved in both phases *ie* been briefed in 1998 that a range of lighting would be installed, they could not possibly know that the 'range' of lighting types mentioned was actually only two, nor where in that continuum their particular lights would be. The likelihood that teachers would consciously, consistently *and intentionally* rate low or high is too improbable to even contemplate.

As a final verification, raw responses were manually allocated into three piles representing low, medium and high ratings for both control and experimental groups. There was an almost equal distribution of ratings into the three piles for the 8 experimental groups, which indicates that these teachers did not bias their evaluations towards the low end of the scale. There was, however, a skewed response in the controls, with obviously more high (negative) and less low (positives) ratings.

4.2 The Psycho-Biological Assessment Scale (PBAS) Development

Other than altering the light source, there was one other absolute requirement for this research: a teacher rating scale by which individual students might be assessed. Given the constraints and sensitivities involved in introducing an experimental factor into the normal teaching day, a scale (the PBAS) eventually emerged which could be quickly (and reliably[10]) completed, since each teacher needed to evaluate between 30 and 35 pupils.

[10] The high statistical reliability of the scale (alpha = .97) was determined twice, once in each phase.

Although standardised child behaviour and ‘state-of-mind’ tests exist, such as the Conners and the Devereux scales, they have to be purchased, with a charge for each child tested; and are not necessarily designed to be rapidly completed. Given the purpose of the current research, some elements of these scales were deemed appropriate to incorporate in a new composite scale, *eg*: measures of attentiveness, aggression, fear, self-esteem and lethargy, *inter alia*. Yet other scales also contain salient elements, *eg*: the Pre-Adolescent Mood Scales used by Wohlfarth, the Kuller/Lindsten scale, and the SADS scale developed during the Westpac study (see: 3.0 FSL Precedents).

It also became evident that many of the items used to assess children in the Conners and Devereux scales were essentially similar, frequently with only the precise wording differing. This allowed the PBAS to be based on a fundamental integration using wording from both. Each item was re-defined using keywords and synonyms, in order to clarify it’s meaning; for instance: Aggressive/angry (fights, argues, threatens, bossy).

Ultimately, five rating scales coalesced into one, *viz*: the **Conners Abbreviated Teachers Rating Scale; Devereux Scales of Mental Disorder (DSMD); Pre-Adolescent Mood Scales (PAMS); Behavioural Observations Scale;** and the **Seasonal Affective Disorder Scale (SADS)** (see also Appendix 2: PBAS Dimensions and Sources).

The integrated schedule incorporates a five-point rating scale (*a la* Devereux) and the 35 ‘items’ (such as distraction, or over-reaction…) are grouped into five dimensions: Inattention, Anxiety, Depression, S.A.D. and Behaviour problems, which are themselves grouped into the Devereux generic categories called the Externalised and Internalised Components.

The issue of the independence of assessors is always problematic. Where teachers assess students there is inevitably an element of subjectivity (as in all psychological tests, whether assessed or self-reported). To attempt to average-out this subjectivity factor a relatively large number of respondents (more than

300 students) were assessed by 12 teachers. “The qualification of a rater is sufficient exposure to a child over the past 4 weeks in order to accurately rate individual behaviour according to the items” (Devereux Manual). Teachers, by definition, have this qualification.

Teachers were requested to also complete a self-assessment mini-questionnaire, based on the S.A.D categories employed previously by the researcher, concerning their sense of well-being, and any experience of headaches or lethargy *ie* symptoms possibly related to the light spectrum.

Statistical analysis of the composite PBAS instrument indicated both a very high reliability and validity *ie* the items were measuring the characteristics they purport to measure, and the clusters of items into the 5 dimensions were all valid. It is considered statistically highly improbable that all items should cluster neatly into the distinct ‘factors’ hypothetically predetermined in the assessment instrument. The fact that this has occurred suggests that the tool is robust and could be used in further research with confidence. The PBAS items are numbered and presented below, for easier reference later.

A	**EXTERNALISED COMPONENT**
Inattention	
A1	Pre-occupied with own thoughts/daydreams
A2	Poor work performance/off-task behaviour
A3	Fidgeting/restless
A4	Inattentive/distracted/poor concentration
A5	Absent-minded/forgetful
A6	Fails to complete activities/short attention span
A7	Does not work independently
A8	Unstimulated/uninterested
Behaviour problems	
A9	Impatient (demands must be met immediately)
A10	Impulsive (acts without thinking, low self control)
A11	Excitable (over-reacts, over-participates)
A12	Disruptive (disturbs, annoys others, talks to others)
A13	Temper tantrums (fails to control anger)
A14	Aggressive/angry (fights, argues, threatens, bossy)
A15	Moods change quickly (unpredictable, flighty)
A16	Irritable (low threshold, edgy)
A17	Frustrated (easily upset, angered, low tolerance)
A18	Hyperactive (talks a lot, moves around, jumps up)
B	**INTERNALISED COMPONENT**
Anxiety	
B1	Fearful (of getting hurt, of strangers, generally)
B2	Upset easily @ own mistakes

B3 Routine wanted (upset @ changes)
B4 Distressed/stressed/tense
B5 Bossed/dominated/bullied
B6 Clingy/dependent

Depression

B7 Participation low
B8 Discouraged/negative
B9 Low self-esteem
B10 Not glad/happy/cheerful/joyous (sad)
B11 Unemotional/unconcerned/indifferent/blank
B12 Low sociability/alone/isolated/withdrawn

S.A.D.

B13 Sleepy during day/yawns/reclines on desk
B14 Sleepy particularly after about 2pm or lunch
B15 Lethargic/not energetic/apathetic/listless
B16 Fatigued/tires easily/weary after effort
B17 Headaches

4.3 Reliability and Validity of the Psycho-Biological Assessment Scale

Once the field experimental situation had been satisfactorily established, the primary issue of concern is the credibility of the assessment instrument. It is the *sine qua non* condition. Accordingly, tests to establish it's construct validity, reliability and internal consistency were undertaken.

The construct validity of the 35-item instrument was established subjecting the data of all 330 Phase#2 cases (control and experimental groups) to the Principal Components Analysis.[11] Before proceeding with the Factor Analysis (Table 1a, over) it was necessary to undertake several preliminary confirmatory tests.

First, the Correlation Matrix (see Appendix 3) was examined to determine whether or not there were correlations amongst the variables. A vast majority of the correlations were high, over 0.5; indeed, some even reached the 0.8 level.

Secondly, it was necessary to determine whether or not the matrix is an 'identity matrix', using Bartlett's test of sphericity. The transformed chi-square value was 14219.341 and the level of significance 0.00000, which means that

[11] Strictly speaking, 'Principal Components Analysis', is the technique applied and 'components' is the terminology which should be used, but because of the widespread use of 'Factor Analysis' and 'factors', the latter semantic usage is followed here. "Factor analysis is perhaps the most powerful method of construct validation" (Kerlinger, 1973:468)

the matrix is not an identity matrix and, thus, clean and interpretable factors are likely to emerge.[12] The level of significance indicates that if the research were replicated there would only be a 1 in 100,000 chance that the result could be due to chance or sampling error.

Finally, the Kaiser-Meyer-Olkin (KMO) measure of sampling adequacy was shown to be 0.95767. The maximum value of this measure is 1.[13]

Consequently, Factor Analysis (Principal Component) was performed on the data.

Table 1a: Factor Analysis: Orthogonal Rotation

[12] If the diagonal values are 1 and off-diagonal values are 0, the correlation matrix is an identity matrix

[13] Kaiser (1974) states that measures above 0.90 are meritorious and those below 0.50 are unacceptable

Rotated Component Matrix[a]

	Component				
	1	2	3	4	5
A14	.807	.166	.352	4.413E-02	.149
A13	.793	.179	.335	.125	.112
A16	.793	.183	.331	.203	.164
A15	.780	.235	.309	.199	.212
A10	.764	.460	2.384E-02	.182	.124
A18	.749	.420	7.922E-02	.123	5.034E-02
A17	.730	.293	.299	.233	.203
A9	.718	.379	-3.30E-02	.307	.141
A12	.696	.523	6.074E-02	.131	.192
A11	.667	.461	-.138	.262	.187
A3	.407	.823	.155	.109	.134
A4	.394	.814	.231	.119	.196
A2	.375	.811	.218	.151	.188
A6	.302	.776	.308	.231	.175
A7	.332	.769	.294	.213	.101
A5	.289	.767	.323	.188	.185
A1	.218	.739	.268	.194	.211
A8	.281	.627	.556	.194	.129
B11	.182	.251	.802	.269	.146
B9	.229	.251	.742	.339	.149
B12	5.560E-02	.225	.714	.389	.208
B10	.188	.213	.703	.350	.244
B8	.325	.365	.684	.296	.161
B7	.281	.438	.684	.217	.108
B6	6.114E-02	.126	.310	.796	5.298E-02
B4	.290	.170	.236	.782	.177
B2	.245	.143	.204	.773	.210
B3	.218	.284	2.887E-02	.752	.156
B5	.141	.168	.342	.715	.184
B1	.136	6.695E-02	.401	.714	.137
B14	.229	.209	.374	.209	.781
B13	.248	.211	.362	.173	.777
B15	.240	.186	.450	.200	.756
B16	.228	.224	.388	.257	.725
B17	6.670E-02	.115	-.170	.112	.634

Extraction Method: Principal Component Analysis.
Rotation Method: Varimax with Kaiser Normalization.

a. Rotation converged in 10 iterations.

From the table it can be seen that 5 factors emerged. The components of each factor were identical to those of the original dimensions determined in the PBAS, indicating a very high measure of construct validity. Ignoring the non-sequential arrangement of the 35 items in the table above, this can be observed by noting how the high figures in each of the 5 columns cluster around the item groups shown previously (p27), *eg* in column1/factor1 from .667 to .807 for the first 10 items shown (A9 to A18 - Behaviour problems), or in column 2/factor 2, from .627 to .823 for items A1-A8 (Inattention), and so on.

As shown in Table 1b, below, as much as 80.5 per cent of the variance is explained by the 5 components or factors, with Factor 1 (Behaviour problems) explaining 55%.

Table 1b: Construct Validity of PBAS Instrument

Factor	Eigenvalue	% of Variance	Cumulative %
1	19.271	55.1	55.1
2	3.566	10.2	65.2
3	1.991	5.7	70.9
4	1.818	5.2	76.1
5	1.524	4.4	80.5

Further analysis showed that the 'communality' of the individual variables, or the variance explained *by each of the 35 items* is also very high, ranging from 0.71 to 0.91; except for variable B17 (headaches) for which the calculated communality is 0.46.

This latter exception is possibly explained by the difficulty of accurately determining whether or not a child had experienced a headache in the past 4-6 weeks – the period of time teachers were asked to reflect on. It is unlikely that teachers consistently asked this, and neither can the child be expected to remember. This is a difficulty inherent in this particular question.

Reliability and internal consistency of the whole instrument were established using Spilt-Half reliability and Cronbach's Alpha tests. The 'stability' of the instrument refers to its reliability, and internal consistency indicates whether the instrument is measuring what it is intended to measure.
To establish stability of the instrument, the split-half reliability (using the 35 items) was calculated. In other words, given that the control and experimental groups are of different sizes, a randomly selected sample of the larger experimental group was taken and compared to the control group. Almost

identical results emerged. Consequently the original Phase#2 data is considered the valid set, and all analyses have been based on it.

Table 2a: Reliability Analysis: *Stability* Scale (Split), PBAS Instrument

Reliability Coefficients	
N of Cases = 316	N of Items = 35
Correlation between forms = .7116	
Guttman Split-half = .8049	Unequal-length Spearman-Brown = .8316
18 Items in part 1 : Cronbach's Alpha = .9732	17 Items in part 2 : Cronbach's Alpha = .9505

The results show four different coefficients of reliability. Since all the coefficients are very large, there is no doubt about the reliability of the instrument.

With regard to **internal consistency,** alpha coefficients below .50 are of questionable reliability, while levels of .70 are satisfactory for the early stages of research and those above .70 possess a high degree of internal consistency (Spuck, 1971).

From Tables 2b and 2c (over) it can be observed that the internal consistency of both the individual items making up the whole instrument, and the five dimensions of the instrument corresponding to the five factors, is very large, ranging from 0.9732 to 0.9758. This indicates a very high degree of internal consistency and thus that the PBAS instrument and the five factors have high validity and are measuring what they purport to measure.

Table 2b: Internal Consistency or *Validity* of the PBAS Instrument, by Item

ITEM	Overall ALPHA (if item deleted)
A1	.9737
A2	.9733
A3	.9735
A4	.9732

A5	.9733
A6	.9732
A7	.9734
A8	.9733
A9	.9738
A10	.9737
A11	.9740
A12	.9736
A13	.9739
A14	.9739
A15	.9736
A16	.9737
A17	.9735
A18	.9739
B1	.9744
B2	.9742
B3	.9743
B4	.9740
B5	.9742
B6	.9745
B7	.9735
B8	.9734
B9	.9737
B10	.9739
B11	.9739
B12	.9741
B13	.9740
B14	.9739
B15	.9739
B16	.9739
B17	.9758

Reliability, All 35 Items: Alpha =.9746 (n=316)

Table 2c: Internal Consistency for Items as Dimensions/Components

Dimensions	Overall Alpha (if item deleted)
A1-A8 (Inattention)	.9740
A9-A18 (Behaviour problems)	.9611
B1-B6 (Anxiety)	.9210
B7-B12 (Depression)	.9498
B13-B17 (S.A.D.)	.9012

In summary, then, the 35 item PBAS instrument has been systematically developed which has led to both construct validity and reliability. The construct validity is obvious due to the fact that all the 35 items have yielded 5 factors explaining as much as 80% of the variance. Not even a single item is misplaced from the original dimensions set up in the scale. The overall stability of the instrument, as indicated by the split-half reliability coefficients, has reached a very high degree, and the instrument has a very high degree of internal consistency. In short, the PBAS instrument appears to be very robust.

5 ANALYSIS and DISCUSSION: Phase #2

Tests for significant differences between the FSL and Control rooms should be understood in the following terms: where $p = \leq .05$ this indicates significance; where $p = \leq .01$ this is highly significant, and where $p = \leq .000$ or .001 it is very highly significant.

Theoretical expectations have been empirically confirmed in this research. The results indicate that states-of-mind or generic performance[14], assumed to correspond to a photon-neuron interaction, *do* vary with the spectral quality of light.

This research did not test respondents on standardised academic performance tests (such as the reading and mathematics tests used in the Leschong and Hathaway research, *op.cit*), nor absenteeism – both once mooted as possible avenues for investigation but overtaken by the overwhelming significance afforded to the psycho-biological dimensions assessed by the scale that had been specifically designed for this research.

Similarly, the individual teacher questionnaire has not been analysed for Phase#2, since it seems confusing now: it is regrettable that numbers were put on the scale, *eg:*-

calm	7	6	5	4	3	2	1	anxious

[14] using 'performance' as a generic category subsuming all the others: inattention, anxiety,

Does circling a 1 mean a low level of anxiety, or does being close to the anxious side of the scale imply a high level? Without numbers it could have been assumed that closer to the anxiety side of the scale would have implied a higher degree of that aspect.

The results presented below are unusual in the sense that they are consistently in the theoretically expected direction *ie* full spectrum light *is* beneficial to performance, over a wide array of parameters.

The significance of the findings and their potential *applied* importance to the school system demanded that they be tested and re-tested as rigorously as possible.

The wording of the PBAS is in the negative (‘fatigued’, ‘distressed’ *etc*) and the rating scale was designed such that 1 = ‘never’ and 5 = ‘very frequently’. The theoretical expectation is thus that the *means* for the experimental FSL group should be *less* than those of the Control group if the light quality-performance quality hypothesis is true. This was found to be the case *for each of the 35 variables* (see Table 3, over).

But are these differences in the means statistically significant? To examine this, the Multivariate Analysis of Variance was conducted (Table 4, p37). When there are multiple dependent variables, if the MANOVA is used it not only answers whether there is statistically significant difference among different groups taking all the variables together, but also whether there are statistically significant difference among different groups on each individual variable.

Four tests were employed, the most powerful being the Pillai’s trace, followed by Hotellings’ T^{2}, Wilk’s Lambda and Roy’s Largest Root, in that order. The results verify that the differences in the means are indeed highly significant, and in the theoretically expected direction.

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depression, lethargy *etc*

Table 3: Means for Both Groups

	Control Group n=110			Experimental Group n=220	
Variable	Mean	Std. Deviation		Mean	Std. Deviation
A1	2.95	1.02		2.25	1.10
A2	2.72	1.09		2.17	1.24
A3	2.76	1.07		2.26	1.22
A4	2.80	1.12		2.13	1.19
A5	2.65	1.10		2.01	1.13
A6	2.68	1.03		2.10	1.25
A7	2.68	1.10		2.09	1.24
A8	2.51	.95		1.84	1.06
A9	2.13	1.00		1.63	1.00
A10	2.18	1.03		1.75	1.11
A11	2.13	1.00		1.81	1.11
A12	2.41	1.17		1.89	1.17
A13	1.73	.79		1.38	.76
A14	1.84	.89		1.38	.78
A15	1.89	.81		1.41	.72
A16	1.97	.89		1.39	.70
A17	2.02	.94		1.51	.82
A18	1.95	.96		1.69	1.05
B1	2.14	.86		1.77	.93
B2	2.15	.87		1.63	.79
B3	1.96	.79		1.89	1.08
B4	1.91	.77		1.55	.84
B5	1.83	.71		1.45	.73
B6	1.87	.77		1.42	.76
B7	2.34	.96		1.73	1.04
B8	2.12	.83		1.63	.90
B9	2.26	.87		1.75	1.04
B10	2.24	.99		1.50	.78
B11	2.19	.93		1.46	.74
B12	2.21	.91		1.55	.85
B13	2.12	.94		1.68	.72
B14	2.17	.91		1.67	.73
B15	2.19	.96		1.63	.72
B16	2.16	.91		1.68	.75
B17	1.95	1.10		1.67	.84

Multivariate Analysis of Variance: Entire PBAS Instrument

At the outset, all the 35 together were considered (Table 4, over).

All the 4 statistical tests were significant beyond the usually acceptable level of 0.05 and 0.01. In fact, the level of significance reached was 0.000. There is, thus, a statistically significant difference between the control and experimental groups when all the 35 variables are taken together. The level of significance indicates that if the research were replicated there would only be a 1 in 1,000 chance that the result could be due to chance or sampling error. Given that the means in respect of every variable in the experimental group are smaller than the corresponding means in the control group, it can be concluded that the full spectrum lighting has the effect of improving performance.

Univariate Analysis of Variance

Univariate results were then examined to ascertain where exactly the differences between the two groups lie.

Overall, it can be noted that there are statistically significant differences between the two groups on all the variables except variable B3 (‘wanting routine’) where the significance failed to reach the usually acceptable level of 0.05. This is possibly due to confusion: is wanting routine negative or positive?

In the case of variables A11 (excitable) and A18 (hyperactive) the significance reached was beyond 0.05 level, while in *all* other cases, the level of significance was again at 0.000 level.

Table 4: Multivariate Analysis of Variance: **All PBAS Variables**

Multivariate Tests

	Value	**F**	**Sig.**
Pillai's Trace	.370	4.692	**.000**
Wilks' Lambda	.630	4.692	**.000**
Hotelling's Trace	.586	4.692	**.000**
Roy's Largest Root	.586	4.692	**.000**

Univariate Test

Dependent Variable	F	Sig.
B13	22.533	**.000**
B14	32.475	**.000**
B15	36.264	**.000**
B16	28.451	**.000**
B17	6.756	**.010**
A1	31.429	**.000**
A2	16.262	**.000**
A3	13.859	**.000**
A4	22.980	**.000**
A5	24.554	**.000**
A6	18.468	**.000**
A7	18.484	**.000**
A8	29.938	**.000**
A9	18.855	**.000**
A10	11.217	**.001**
A11	4.937	**.027**
A12	13.614	**.000**
A13	13.862	**.000**
A14	24.606	**.000**
A15	29.606	**.000**
A16	41.765	**.000**
A17	24.835	**.000**
A18	4.781	**.030**
B1	12.497	**.000**
B2	27.765	**.000**
B3	.716	**.398***
B4	14.419	**.000**
B5	18.606	**.000**
B6	24.276	**.000**
B7	26.725	**.000**
B8	23.091	**.000**
B9	19.023	**.000**
B10	50.835	**.000**
B11	59.463	**.000**
B12	40.946	**.000**

* not significant

Tables 5: Multivariate and Univariate Analysis for Each Dimension

<u>Table 5a:</u> Variables A1 – A8 **(Inattention)**

Multivariate Tests

Test	Value	F	Sig.
Pillai's Trace	.131	5.873	**.000**
Wilks' Lambda	.869	5.873	**.000**

Hotelling's Trace	.151	5.873	**.000**
Roy's Largest Root	.151	5.873	**.000**

Univariate Test

Dependent Variable	**F**	**Sig.**
A1	32.859	**.000**
A2	17.190	**.000**
A3	14.230	**.000**
A4	24.087	**.000**
A5	24.930	**.000**
A6	19.428	**.000**
A7	19.442	**.000**
A8	31.092	**.000**

Inattention

All 4 Multivariate tests are significant beyond the usually acceptable significance of 0.05 and 0.01. In fact, the level of significance reached is 0.000. Therefore, there is a statistically significant difference between the control and experimental groups when all the 8 variables are taken together. Given that the mean in respect of every variable in the experimental group is smaller than the corresponding mean in the control group, the full spectrum light is having a positive affect on attention.

There are also statistically significant Univariate differences at the 0.000 level between the two groups in the case of all the 8 variables and, therefore, all the variables are contributing to the difference**.**

<u>Table 5b:</u> Variables A9-A18 **(Behaviour Problems)**

Multivariate Tests:

	Value	**F**	**Sig.**
Pillai's Trace	.171	6.480	**.000**
Wilks' Lambda	.829	6.480	**.000**
Hotelling's Trace	.206	6.480	**.000**
Roy's Largest Root	.206	6.480	**.000**

Univariate Test

	Dependent Variable	**F**	**Sig.**
	A9	17.381	**.000**
	A10	11.270	**.001**
	A11	5.948	**.015**
	A12	13.812	**.000**
	A13	14.659	**.000**
	A14	23.305	**.000**
	A15	31.147	**.000**
	A16	42.586	**.000**
	A17	25.279	**.000**
	A18	4.435	**.036**

Behavioural Problems

All 4 Multivariate tests are significant at 0.000 level. Therefore, there is a statistically significant difference between the control and experimental groups when all the 10 variables are taken together. Given the differences between the means, it is feasible to conclude that the FSL lights lower the intensity of behavioural problems.

Examining the Univariate results to ascertain where exactly the differences between the two groups lie, it is evident that other than A11 and A18, which are significant at the 0.05 level, the differences are at 0.000 level. All 10 variables are contributing to the difference.

Table 5c: Variables B1-B6 **(Anxiety)**

Multivariate Tests

	Value	**F**	**Sig.**
Pillai's Trace	.150	9.498	**.000**
Wilks' Lambda	.850	9.498	**.000**
Hotelling's Trace	.177	9.498	**.000**
Roy's Largest Root	.177	9.498	**.000**

Univariate Test

Dependent Variable	F	Sig.
B1	12.087	**.001**
B2	28.593	**.000**
B3	.453	**.501 ***
B4	14.014	**.000**
B5	19.603	**.000**
B6	25.607	**.000**

* = not significant

Anxiety

All 4 Multivariate statistical tests are significant at 0.000 level. Again, there is a significant difference between the control and experimental groups when all the 6 variables are taken together. Given the differences between the means, it is possible to conclude that the FSL lights lower anxiety.

The Univariate results again indicate very significant differences between the two groups in the case of all but variable B3, which is not significant. All the other 5 variables are thus contributing to the difference.

Table 5d: Variables B7-B12 **(Depression)**

Multivariate Tests

	Value	F	Sig.
Pillai's Trace	.190	12.586	**.000**
Wilks' Lambda	.810	12.586	**.000**
Hotelling's Trace	.235	12.586	**.000**
Roy's Largest Root	.235	12.586	**.000**

Univariate Test

Dependent Variable	**F**	**Sig.**
B7	26.570	**.000**
B8	22.263	**.000**
B9	19.256	**.000**
B10	52.256	**.000**
B11	59.493	**.000**
B12	42.335	**.000**

Depression

As in the case of the other components of the PBAS, all 4 Multivariate tests are highly significant when all 6 variables taken together. The FSL lighting is observed to diminish depression.

Univariate results indicate significant differences at 0.000 level between the two groups in the case of all the 6 variables.

<u>Table 5e</u>: Variables B13-B17 **(S.A.D.)**

Multivariate Tests

Test	**Value**	**F**	**Sig.**
Pillai's Trace	.105	7.574	**.000**
Wilks' Lambda	.895	7.574	**.000**
Hotelling's Trace	.118	7.574	**.000**
Roy's Largest Root	.118	7.574	**.000**

Univariate Test

Dependent	**F**	**Sig.**

Variable		
B13	21.172	**.000**
B14	29.569	**.000**
B15	34.197	**.000**
B16	26.099	**.000**
B17	6.784	**.010**

S.A.D.

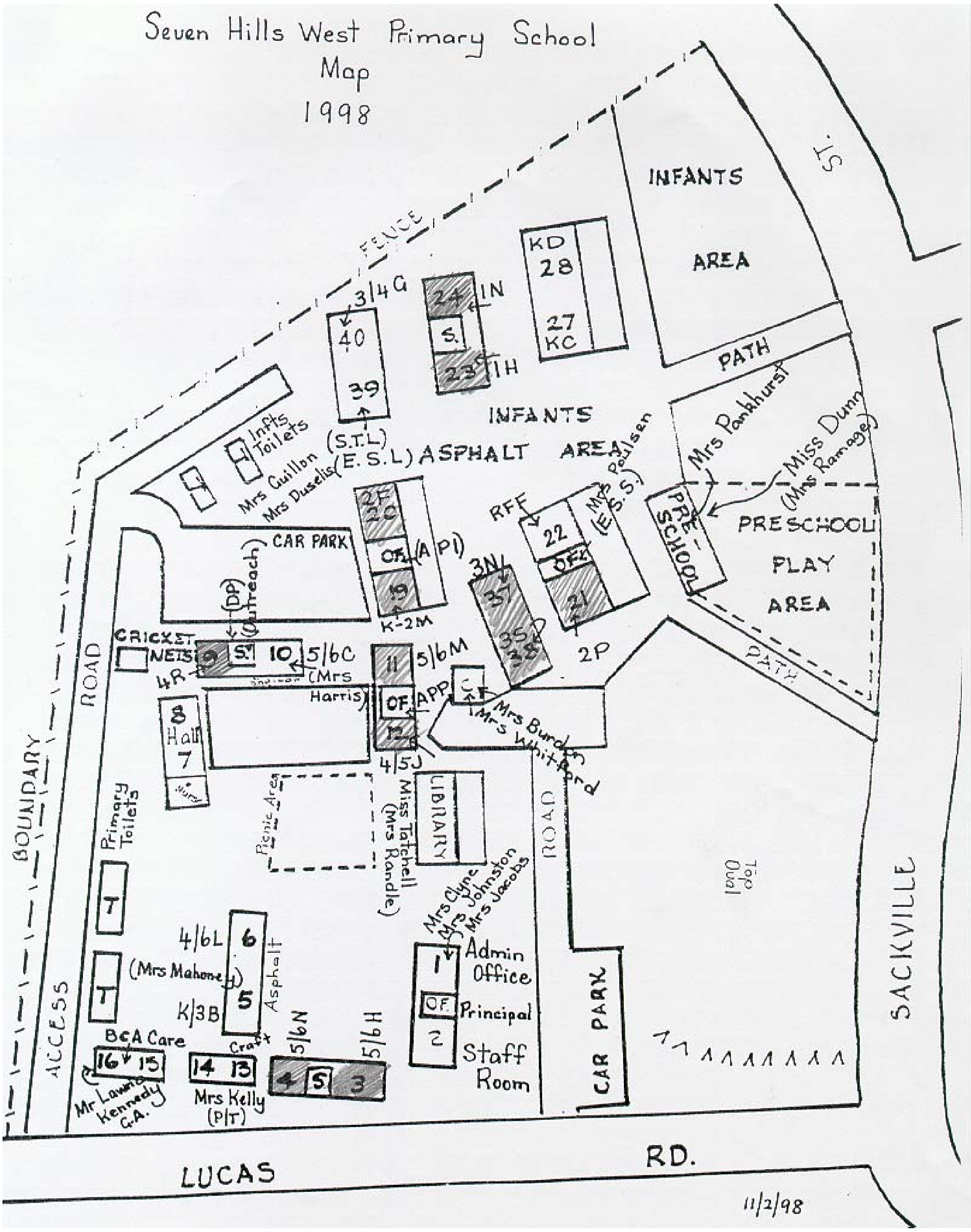
Again, all 4 tests are significant at 0.000 level for these 5 variables. Full spectrum lighting reduces Seasonal Affective Disorder syndromes.

Univariate results indicate significant differences at 0.000 level between the two groups in the case of 4 variables, while B17 is significant but not at this very elevated level. All the variables are contributing to the differences between the control and experimental groups.

Summary

The results follow a pattern similar to the instrument validity and reliability tests. Not only did the Multivariate Analysis indicate that the full spectrum lighting condition positively influences generic performance to a very significant degree, the Univariate results repeat this pattern of high statistical significance for each aspect tested by the PBAS (except for the ‘routine wanted’ variable which, nonetheless, displays the same trend and is in the predicted direction).

Typical view: Seven Hills West Primary School classrooms:
(note: typical shading regime)



Map of School: showing 12 classrooms N⇑

(Control rooms = 3, 4, 9, 21)

6 CONCLUSION

The research reported here is the culmination of a decade of investigation, sparked by an initial interest in an apparatus called a Lumitron which is able to assess 'visual field colour deficiencies' in people (Downing, 1988 and 1996, Liberman, 1985). A deeper theoretical investigation into light and well-being followed, unearthing research in photo-biology from its origins more than 30 years ago (Wurtman, Hollwich, Ott, Birren, Boyce, Neer, Lewy and Wohlfarth, *inter alia*, in the 70s and 80s, crystallising in a special publication by the New York Academy of Sciences in 1985). In 1992 the theory was put to test in Australian conditions, by the researcher, in an office building in Sydney, with encouraging results relating to diminished headaches and lethargy in the full spectrum conditions. A theoretical report on Colour and Light in Schools was later commissioned by the DPWS (Samuels and Stephens, 1996), which formed the basis for the Seven Hills West research reported here. Recently, the vital arena of research in schools seems to be centred in North America, with Hathaway's 1995 development of Wohlfarth's earlier work in Canada, and Leschong's 1999 work on daylight in American schools.

The essential central ingredient of all this research concerns the photon-neuron interaction, and its translation into practical applications in the built environment – in the form of daylighting and artificial lighting in buildings – is the ultimate objective.

Also implicated is the issue of energy efficiency. Although enhancing natural daylighting has obvious energy consequences, the question of the extent to which this *interior daylight* replicates natural full spectrum light has not been addressed. As far as artificial lighting is concerned, it is inadequate to simply cite the relatively lower efficiencies of full spectrum or daylight-simulating fluorescent lighting without a deeper appreciation of the importance of the quality of light spectra on human functioning. Energy management strategies, in any event, can compensate here (see Recommendations).

The research reported here has integrated salient elements of the theoretical and empirical work conducted 'overseas' over many years; extracted (hypothetically) key elements from standardised child-personality assessment scales *not previously used* in FSL research, and integrated them with elements from scales which *have* been used to assess school children in such conditions (such as the PAMS). This resulted in a unique 35 item evaluation instrument – here shown to be reliable and valid and, given the high levels of significance which have emerged, apparently an appropriate method to measure whether light spectra influence generic performance - manifested as inattention, lethargy, self-esteem and so on. The rationale for testing in ‘sunny’ Australian conditions rests on the fact that northern hemisphere countries have longer, colder winters, thus more indoor-oriented lifestyles and lower daylight exposure - with a greater incidence of light deprivation syndromes to be expected.

Positive affects of exposure to full spectrum light emerging from overseas studies which relate to dental caries, catarrhal infections, secretions of cortisol, hyperactivity, visual acuity and academic performance, *inter alia*, have not yet been replicated in Australian conditions.

In the research reported here, much attention has been given to the generation of a field experimental condition that most closely represents the natural state of affairs, in full recognition of the disruptive influence interventions have, and the confounding consequences for the interpretation of research results. A minimalist approach has been adopted, *viz*: consciously altering only one variable, and trusting that the multitude of other variables possibly playing a role would naturally ‘average-out’ across the sample. Thus, socio-economic, ethnic and family dynamics, personal proclivities and states of health, and so on, are not considered as part of the equation but left as background, neutral in the sense that they are taken as given. Notwithstanding, the Phase#1 research was beset by difficulties which proved unavoidable and, indeed, the Interim Report (which should be read in conjunction with this Final report) contains several pages of constraints which might have influenced the findings. Despite these misgivings, definite trends did emerge, in the theoretically expected direction, but amid some confusion. Serendipitously, however, the Phase#2 research was able to proceed unobtrusively, without any intervention in the routine conditions prevalent at the school. This undreamed of opportunity thus converted the research from a field interventionist to a post occupancy evaluation, where user experience continues undisturbed in the natural conditions.

The happy co-incidence of a robust assessment instrument and an undisturbed setting seems to have paid off, with definitive and lucid findings verifying the positive influence of full spectrum light on ‘the human condition’. Virtually every category of generic performance investigated here appears to have been strongly influenced.

Nevertheless, a healthy dose of skepticism is definitely required, albeit such a clear result has emerged (indeed, because of it). We are still in the realm of hypothesis, since this is the first time this particular strategy has been applied; and it is surely prudent to repeat the study in some form or other, to validate the findings. But, simultaneously, there is nothing to lose in beginning to apply the insights to school conditions (see Further Research); no disbenefits have ever emerged, and recent research which claims to find no affects is here considered spurious (discussed earlier). The Seven Hills West results only confirm, albeit dramatically, the trends displayed in many decades of prior research.

It now seems reasonable to conclude that light and human functioning are intimately related; and that this is an intrinsic interaction of profound significance to environmental design. Hence, the more daylight and daylight-simulating artificial lighting which can be provided the better attentiveness, mood, satisfaction, behaviour and health are likely to be. Why then should full spectrum lighting not be installed in schools, hospitals, offices and universities, or prisons?

Ultimately the light-performance insight becomes an issue of ensuring *full spectrum daylight* penetration inside buildings, and/or its provision artificially - particularly since exponentially accelerating urbanisation means more people spend more time indoors than ever before. Re-lamping schools with full spectrum lighting will involve an added cost; yet, not only would economies of scale be expected, but any added expense could only be minor in comparison to the potential benefits which would accrue. Life is adapted to light.

6.1 Recommendations, and Further Research

If conditions permit intervention at the drawing board stage, luminaires could be hung lower, and be equipped with reflectors, to ensure that 400 to 500 lux of full spectrum light falls at desk height. This might also allow for the removal of a lamp from time to time, thus enhancing efficiency.

If it were possible to equip an entire primary school with full spectrum lighting, it could be compared to others with standard issue lighting, to establish to what degree the dominating findings from the Seven Hills West research are repeated. In high school conditions, where students do not have one class teacher, perhaps they could be assessed on different criteria, such as standardised academic performance tests. Further developments could include the painting of some classrooms blue or, indeed, an entire school; and the influence of enhanced UVA radiation could be evaluated by the simple strategy of ensuring that luminaires can be fitted with egg-crate diffusers, which block less UV emission.

Notwithstanding the further development and testing of the research reported here, it is recommended that the Department of Education and Training and the Department of Public Works and Service give serious consideration to the installation of full spectrum lighting in the buildings for which they are responsible.

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APPENDICES

APPENDIX 1   PBAS SCALE

(over)

PSYCHO-BIOLOGICAL ASSESSMENT SCALE (PBAS) - Composite Rating Scale

	1 Never	2 Rare	3 Occasional	4 Frequent	5 Very Freq.
A EXTERNALISED COMPONENT					
Inattention					
• Pre-occupied with own thoughts/daydreams					
• Poor work performance/off-task behaviour					
• Fidgeting/restless………………………………….					
• Inattentive/distracted/poor concentration					
• Absent-minded/forgetful…………………………..					
• Fails to complete activities/short attention span					
• Does not work independently……………………..					
• Unstimulated/uninterested					
Behaviour problems					
• Impatient (demands must be met immediately)					
• Impulsive (acts without thinking, low self control)					
• Excitable (over-reacts, over-participates)…………					
• Disruptive (disturbs, annoys others, talks to others)					
• Temper tantrums (fails to control anger)………….					
• Aggressive/angry (fights, argues, threatens, bossy)					
• Moods change quickly (unpredictable, flighty)					
• Irritable (low threshold, edgy)…………………….					
• Frustrated (easily upset, angered, low tolerance)					
• Hyperactive (talks a lot, moves around, jumps up)					
B INTERNALISED COMPONENT					
Anxiety					
• Fearful (of getting hurt, of strangers, generally)					
• Upset easily @ own mistakes……………………..					
• Routine wanted (upset @ changes)					
• Distressed/stressed/tense………………………….					
• Bossed/dominated/bullied					
• Clingy/dependent					
Depression					
• Participation low…………………………………..					
• Discouraged/negative					
• Low self-esteem…………………………………...					
• Not glad/happy/cheerful/joyous (sad)					
• Unemotional/unconcerned/indifferent/blank					
• Low sociability/alone/isolated/withdrawn					
S.A.D.					
• Sleepy during day/yawns/reclines on desk					
• Sleepy particularly after about 2pm or lunch					
• Lethargic/not energetic/apathetic/listless………….					
• Fatigued/tires easily/weary after effort					
• Headaches *(please ask student, if unknown*					

APPENDIX 2: PBAS (5 Dimensions)

Behaviour, Attention, Anxiety, Depression, SAD

based on elements extracted from the following:-

* **Conners Abbreviated Teachers Rating Scale**

see: Sprague, R. Cohen, M. & Weary. J, 1974, *Normative Data on Conners Teachers Rating Scale and Abbreviated Scale,* Technical Report, Children's Research Centre, University of Illinois, Urbana. Also Conners, C.K. (1969), *A Teacher Rating Scale for Use in Drug Studies with Children,* Am. J. Psychiatry, 126, 884-885.

* **Devereux Scales of Mental Disorder (DSMD)**

see Naglieri, J., LeBuffe, P & Pfeiffer, S. (1994), *Devereux Scales of Mental Disorders Manual*, The Psychological Corporation, Harcourt Brace, San Antonio {scales for ages 5-12, evolving from Devereux Child Behaviour Rating Scales} (Spivack & Spotts, 1966;]

* **Pre-Adolescent Mood Scales (PAMS)** (grades 1-6)

see Schokman-Gates, K. (1984), *The Pre-Adolescent Mood Scale: Development and Validation*, Unpublished Ph.D. thesis, University of Alberta, Edmonton, Canada.

See also Wohlfarth, H. (1986), *Colour and Light Effects on Students Achievement, Behaviour and Physiology,* Alberta Education, Edmonton.

* **Behavioural Observations Scale**

see Kuller and Lindsten, 1991, *Health Effects of Work in Windowless Classrooms,* Report no.10, Swedish Council for Build. Research, Stockholm.

* **Seasonal Affective Disorder/Photo-PsychoSomatic Scale (SAD/PPSS)**

see Samuels, (1992), Quality and Efficiency in Lighting, Final Research Report for Pacific Power, Solarch, Faculty of Architecture, UNSW, Sydney.

APPENDIX 3: Correlation Matrix

	A1	A2	A3	A4	A5	A6	A7
A1	1.00000						
A2	.81501	1.00000					
A3	.80590	.90137	1.00000				
A4	.83750	.91809	.91683	1.00000			
A5	.80932	.86034	.82735	.88395	1.00000		
A6	.74845	.87247	.82598	.86925	.85271	1.00000	
A7	.70191	.83723	.81174	.83603	.79684	.89406	1.00000
A8	.68658	.75992	.72745	.78374	.78932	.83061	.82670
A9	.48839	.64605	.63280	.63954	.54767	.57574	.59827
A10	.53139	.68875	.72846	.70133	.59455	.64308	.67425
A11	.50238	.63129	.66410	.64849	.54450	.57849	.60342
A12	.57197	.73626	.74844	.74052	.63023	.68642	.71149
A13	.49189	.57431	.56527	.59435	.52647	.56392	.53716
A14	.45658	.54655	.55168	.58429	.53023	.55711	.54675
A15	.55447	.63732	.60650	.65706	.62201	.60188	.59052
A16	.50236	.59800	.58056	.61367	.59000	.56425	.55338
A17	.59486	.67673	.62748	.68185	.66260	.62583	.60883
A18	.48327	.64564	.68623	.64449	.57470	.59233	.61987
B1	.38195	.32238	.28509	.33001	.37511	.40143	.38803
B2	.44416	.42002	.36260	.39886	.45682	.48877	.41970
B3	.39995	.44218	.41966	.42605	.47273	.48080	.49082
B4	.47765	.45644	.41076	.44858	.47968	.50050	.44913
B5	.42659	.43329	.35983	.39732	.43637	.49361	.44796
B6	.33373	.31744	.27749	.30311	.37274	.41255	.41244
B7	.58585	.64301	.59532	.64320	.65933	.71528	.70558
B8	.58707	.63632	.58484	.63452	.66105	.65260	.66045
B9	.49531	.51450	.46746	.52189	.56574	.59385	.55960
B10	.53127	.51387	.43573	.50930	.54597	.52723	.51096
B11	.54015	.50923	.47114	.52238	.58570	.54430	.53626
B12	.46559	.45342	.38374	.44844	.51163	.52660	.49909
B13	.49893	.51395	.44684	.51724	.52781	.52134	.47473
B14	.49180	.50209	.45357	.51467	.52971	.53827	.47919
B15	.49474	.51332	.45240	.51359	.52636	.53834	.48996
B16	.49266	.51717	.47007	.52656	.52891	.56197	.50358
B17	.22111	.22235	.18149	.23338	.19494	.19081	.14173

	A8	A9	A10	A11	A12	A13	A14
A9	.48867	1.00000					
A10	.54571	.83496	1.00000				
A11	.48210	.78258	.83360	1.00000			
A12	.60203	.74847	.85762	.79147	1.00000		
A13	.55778	.62146	.69416	.57055	.64067	1.00000	
A14	.57481	.61386	.68585	.54235	.69202	.83548	1.00000
A15	.61219	.68654	.71011	.64279	.69228	.83155	.81553
A16	.59553	.70045	.69791	.60088	.67193	.79983	.80292
A17	.61308	.70129	.72892	.61719	.71158	.78352	.77162
A18	.53784	.72129	.80931	.74860	.82285	.64638	.67625
B1	.47085	.31547	.29462	.26698	.27138	.35920	.33175
B2	.45467	.43497	.38091	.41252	.39486	.41376	.37773
B3	.41528	.50454	.48666	.49615	.40514	.34815	.27512
B4	.51487	.51518	.44723	.44486	.42182	.48224	.42516
B5	.50833	.34103	.31428	.33090	.37116	.38975	.36733
B6	.41617	.37710	.25406	.26569	.24623	.27591	.23024

B7	.77762	.43215	.50336	.41050	.54221	.55470	.53708
B8	.76922	.46488	.52099	.43393	.54758	.59553	.55733
B9	.68294	.35557	.43253	.33751	.45045	.51665	.47873
B10	.63948	.40048	.36440	.28439	.37122	.49272	.47712
B11	.71754	.34415	.36268	.24248	.36979	.46921	.48258
B12	.62855	.30523	.32093	.22707	.31596	.37757	.36180
B13	.52730	.40255	.43362	.41605	.49560	.43524	.47950
B14	.53845	.41834	.43285	.42577	.47999	.43584	.47016
B15	.57397	.41351	.41555	.39179	.46509	.46143	.48504
B16	.58316	.42616	.44995	.40506	.48238	.45057	.47450
B17	.11511	.19224	.15151	.20875	.19675	.18746	.14422

	A15	A16	A17	A18	B1	B2	B3
A15	1.00000						
A16	.88166	1.00000					
A17	.82994	.83572	1.00000				
A18	.69404	.68468	.66157	1.00000			
B1	.40642	.42533	.42624	.25732	1.00000		
B2	.50496	.49668	.53597	.35366	.72051	1.00000	
B3	.43539	.39988	.44465	.37742	.62085	.67073	1.00000
B4	.53322	.52068	.56859	.38983	.66651	.74927	.68478
B5	.44517	.42736	.47444	.29606	.60741	.67392	.53169
B6	.34884	.36436	.35595	.24328	.65604	.64928	.57554
B7	.57990	.55820	.59704	.49075	.52515	.46772	.41110
B8	.61279	.61681	.63604	.52618	.59096	.50830	.47265
B9	.52711	.52658	.53845	.44425	.60231	.52835	.41763
B10	.52135	.52021	.53240	.32840	.53107	.51327	.44682
B11	.54025	.53980	.53497	.33801	.57334	.49953	.39422
B12	.42809	.40942	.41368	.28455	.53089	.49209	.41185
B13	.53938	.49670	.56329	.37700	.44331	.47921	.38343
B14	.53842	.48639	.53082	.37044	.47156	.49785	.42134
B15	.55919	.54855	.55409	.36998	.48035	.47910	.40047
B16	.52337	.51408	.53401	.39746	.48429	.48053	.44880
B17	.22838	.18064	.18916	.09907	.08648	.20649	.16337

	B4	B5	B6	B7	B8	B9	B10
B4	1.00000						
B5	.78117	1.00000					
B6	.68535	.71740	1.00000				
B7	.49842	.49041	.44930	1.00000			
B8	.57331	.54892	.50418	.85711	1.00000		
B9	.56742	.58006	.53304	.80375	.85584	1.00000	
B10	.59077	.56520	.55348	.68324	.75615	.73196	1.00000
B11	.50303	.51442	.49698	.76129	.77009	.75764	.81766
B12	.54457	.63119	.59024	.64999	.69158	.78426	.76286
B13	.44122	.46636	.33372	.54407	.58722	.56818	.56003
B14	.46699	.47081	.36275	.53873	.58300	.55147	.59759
B15	.49938	.49546	.37832	.57201	.60326	.59710	.63562
B16	.53120	.51213	.43138	.54809	.58576	.57609	.59563
B17	.22297	.17613	.11088	.10228	.17385	.11055	.17956

	B11	B12	B13	B14	B15	B16	B17
B11	1.00000						
B12	.76154	1.00000					
B13	.53692	.51615	1.00000				
B14	.56869	.56594	.90012	1.00000			
B15	.61355	.60945	.87159	.89702	1.00000		
B16	.56310	.60103	.81707	.86567	.91817	1.00000	
B17	.04356	.09340	.38475	.35368	.33836	.32345	1.00000