節能玻璃遮陽性能耐候特性之研究

內政部建築研究所協同研究報告

中華民國 97 年 12 月

節能玻璃遮陽性能耐候特性之研究

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摘 要

關鍵詞：建築節能、節能玻璃、耐候性能

一、研究緣起

經由九十二年度「建築外殼性能檢測分析研究」、「建材性能檢測分析實驗研究」、九十三年度「建築外殼隔熱性能檢測標準化之研究」、九十四年度「單一建材隔熱性能資料庫之建立」、「熱環境實驗室性能評估與 CNLA 認證之建立」以及九十五年度「建築節能法令之建材熱傳與光學性能標準之研究」等計畫之研究成果，內政部建築研究所業已完成建築外殼隔熱性能檢測、隔熱膜熱傳導係數與玻璃光學性能之量測裝置與標準程序，使得性能實驗中心熱環境實驗室取得 TAF 量測實驗室之認證。不僅對於「建築節約能源設計技術規範與實例」中之各式建材隔熱性能表格內之數據提出修訂與建議，對於我國在推行「綠建築標章」之日常節能指標具有相當的貢獻度。並且配合中華建築中心綠建材專案小組完成「高性能節能玻璃綠建材解說與評估」之訂定。

綜合上述研究計畫成果，熱環境實驗室在玻璃建材之光學性質與熱學性質方面已具備單層平板玻璃、膠合玻璃與複層玻璃之量測能力；同時亦具有利用 WINDOW 5.2 程式將單層平板玻璃與空氣層組合成各式複層玻璃，並求出其光學與熱學性能之研發能力。

再者，在 96 年度之研究計畫成果中，研究團隊發現影響膠合與複層玻璃之光學性質之主要參數為膠膜；而此類玻璃，無論是直接塗覆在玻璃表面的 Low-E 玻璃或是夾在兩層玻璃之間的膠膜均是關鍵。而且對於複層玻璃而言，中間隔熱膜性能以及複層玻璃密封性對於遮蔽係數（SC 值）之影響甚大。故對於本年度研究計畫之研究主題將訂定為膠膜對節能玻璃遮陽性能之探討。

本年度研究主題延續 92～96 年度之研究方向，研究對象亦為節能玻璃建材。根據 92~96 年度研究計畫之結果顯示，建築節能隔熱材料已受世界各國重視而蓬勃發展，以玻璃建材為例，低輻射Low-E玻璃已成為現今建築廣泛使用之建材之一。全世界Low-E玻璃的年均用量已達 1.2 億m^2，歐洲部分國家正在立法鼓勵使用Low-E玻璃，日本和美國的相關產業協會亦採取一定的措施，鼓勵加大Low-E玻璃的普及程度。再者，有關隔熱塗料，奈米光觸媒潔淨塗料等亦被大量

開發生產。然而，對於上述該類節能玻璃通常僅在產品出廠時，進行有關的遮陽與隔熱性質檢驗，對於日後實際使用於建物中，受氣候、光照等影響建材之遮陽與隔熱性能部分並未被深入探討。因此，計畫研究目標為完成節能玻璃遮陽性能耐候特性之影響評估。

二、研究方法及過程

本研究計劃案之進行將採取國際標準探討與實驗印證兩種方式，其主要工作內容首先是玻璃耐候性能之量測標準探討，在確認量測標準後，將進行玻璃耐候性能測試。由於玻璃耐候性能測試之測試時間冗長，因此為瞭解玻璃之耐候程度，在耐候性能測試進行一段時間後，將會先停止耐候試驗，而量測玻璃建材之光學性能以確認受測玻璃試件之光學性能是否已受氣候之影響而產生劣化。本研究計畫在耐候測試部分共有(1) 全尺度室外曝曬實驗、(2) 鉛筆硬度試驗、(3) 耐候性試驗、(4) 耐磨耗性試驗、(5) 耐酸性試驗、(6) 耐鹼性試驗、(7) 玻璃光照試驗等七項試驗項目。

三、重要發現

本研究計畫於執行期間，首先透過相關CNS玻璃建材之定義與檢測方法，探討各種玻璃建材中會影響其耐候特性之因素，了解目前影響玻璃耐候特性的因子計有(1) 雙層玻璃之密封膠、(2) Hard Low-E 鍍膜、(3) 隔熱貼膜以及(4) 光觸媒塗膜。因而依據玻璃耐候性能檢測法訂定相關之檢測項目。研究結果顯示隔熱膜的貼附會在日照下有氣泡而影響其耐候性，再者，隔熱膜的硬度以及耐酸鹼等耐候特性亦不符合CNS的要求。而且由碳弧燈曝曬加速老化實驗中，吾人更發現隔熱膜貼附在玻璃上因為未有任何表面硬化處理，而致使隔熱膜產生劣化而使可見光穿透率大大降低。而對於雙層玻璃之密封膠對於玻璃耐候性部分，在雙層玻璃分別以矽利康以及熱熔膠密封受到碳弧燈曝曬加速老化實驗後之結果發現，熱熔膠並不能承受曝曬實驗的模擬氣候條件，而有軟化以及拉伸強度不足等現象產生。

本研究除了獲得影響玻璃建材耐候性能之因子外，在研究計畫中的光照實驗結果上，研究團隊發現Low-E膜在室外側時的玻璃室內側溫度會比Low-E膜在室內側時的玻璃溫度還低。此玻璃表面溫度的差異，雖然不會影響直設進入玻璃的太陽輻射強度，但卻會影響藉由熱傳導形式進入室內的熱量，以及靠近玻璃附近人員之舒適性。

四、主要建議事項

根據研究發現，本研究針對行政檢查業務委託民間辦理處理的法制化，提出下列具體建議。以下分別從立即可行的建議、及長期性建議加以列舉。

立即可行之建議

主辦機關：內政部建築研究所

由本研究計畫之成果可知，玻璃建材的耐候性能上之最重要影響因素為隔熱膜的耐候性，故對於玻璃建材或隔熱膜的耐候性量測實屬必要。因此建議性能實驗中心可建立氙弧燈曝曬加速老化試驗，藉由此標準量測程序之建立，使得性能實驗中心具有玻璃建材、隔熱膜或相關塗料之耐候性測試技術。

長期性建議

主辦機關：：內政部建築研究所

在本研究計畫中對於光觸媒塗層玻璃之耐候性能試驗上仍屬缺乏，世界各國對於光觸媒玻璃之耐候性能並未有相對應的試驗方法與規範公布。雖然本研究計畫透過相關業者之協談與其他標準探討後，列出相關之規範，但是針對光觸媒玻璃之親水性與光觸媒塗層附著力試驗等方法仍須進一步之探討與建立，故此部分可列為後續之研究主題，期使光觸媒在節能玻璃之應用上能因試驗方法與規範之確立，而能被更廣泛應用在建築玻璃上。

ABSTRACT

Keywords: energy-saving, glass material, weather-resisted performance

This project continue the「Experimental Study for the Performance Test and Analysis of Building Materials (II)」,「Improvement of Isolated Test for the Construction Material of the Building Envelope」, 「Establishment of Thermal Properties Data Base for the Construction Material of the Building Envelope」 conducting the experiments to study the deterioration performance of various energy-saving glass materials of the building envelope.

The authors conducted the measuring technique based on ASTM G93-96, D4329-92 by using the Fluorescent UV Apparatus (UV Accelerated Weathering Tester) and optical performance testing instruments to evaluate the weather deterioration performance of energy-saving glass materials due to short-wave sunlight. On the other hand, the direct exposure of nonmetallic materials to the environment based on ASTM G7-97 was also executed in this project. Different types of glass window, clear glass, tinted glass, reflective glass, double pane glass, and low-e glass were investigated.

The experimental results showed that the bubbles were appeared in the glass adhered with thin film after the direct exposure of specimens to the environment was conducted. This phenomenon indicated that the optical performance of the glass attached with thin film is deteriorated. It is also found from the experimental results of hot-box experiment that the interior surface temperature is higher than exterior surface temperature as the thin film is adhered on the surface toward room. Therefore the PPD values due to surface temperature effect were increased as the thin film is adhered on the surface toward room. On the other hand, adhered films toward to the outdoor cause the PPD values due to surface temperature effect decrease.

第一章 緒論

第一節 研究動機與目的

現代建築設計中，因透光性與設計美學之考量使得玻璃圍幕外牆獲得廣泛的應用；但隨著節約能源與綠建築概念日益獲得重視，使得玻璃圍幕外牆因其在建築節能中的高耗能與光污染等問題而受到較大的質疑。然而近年來國際間對於玻璃圍幕外牆應用的深入探討與研究，使得圍幕外牆的節能措施已成為建築節能之重要一個環節。但是大多數的建築師僅定性了解玻璃建材的光學與熱學性質對建築耗能之影響，因此如何定量分析和改善圍幕外牆的節能方法和效益即為目前重要之研究課題。

目前台灣空調型建築之節能指標為建築物外殼耗能指標ENVLOAD，ENVLOAD 計算公式與建築外殼之隔熱性能有密切之關係。

由下式之 ENVLOAD 公式可知，L 與 Mk 均與建築物玻璃建材之熱學與光學性能有關。

$$ENVLOAD = a_0 + a_1 \times G + a_2 \times L \times DH + a_3 \times \sum Mk \times IHk$$

其中：L 代表建築外殼的熱損失係數

Mk 代表日射取得係數。

玻璃建材在建築物節能部分可區分為遮陽效能與保溫效能兩方面。所謂遮陽效能係指玻璃建材阻擋太陽輻射進入室內之部分，其評估指標為日射取得係數。保溫效能是指熱能經熱傳導、對流穿透玻璃建材，其評估指標為熱穿透係數－U 值。

目前在「建築節約能源設計技術規範與實例」中之常用玻璃熱傳透率 U 值與玻璃之日射透過率 i 值等兩部分數據已修正為台灣當地本土玻璃建材之量測數據，上述節能法規所列數據之適用性確已於 96 年度研究計畫中探討。

建築節能隔熱材料已受世界各國重視而蓬勃發展，以玻璃建材為例，低輻射Low-E玻璃已成為現今建築廣泛使用之建材之一。全世界Low-E玻璃的年均用量已達 1.2 億m^2，歐洲部分國家正在立法鼓勵使用

Low-E玻璃，日本和美國的相關產業協會亦採取一定的措施，鼓勵加大Low-E玻璃的普及程度。再者，有關隔熱塗料，奈米光觸媒潔淨塗料等亦被大量開發生產；在96年度之研究計畫成果中，研究團隊發現影響膠合與複層玻璃之光學性質之主要參數為膠膜。然而，對於上述該類節能玻璃通常僅在產品出廠時，進行有關的遮陽與隔熱性質檢驗，對於日後實際使用於建物中，受氣候、光照等影響建材之遮陽與隔熱性能部分並未被深入探討。因此本研究計畫之研究目的乃在探討節能玻璃建材中隔熱膠膜以及塑膠密封材料受氣候、光照之影響，並且進一步以先期研究計畫建立之玻璃光學性質量測儀器進行節能玻璃耐候特性對其遮陽性能量測。期使本研究成果對我國建築使用節能玻璃應有相當程度的貢獻，對於提昇國內建築外殼省能之推展與促進本土化優良建材產業之發展也有正面的幫助。

根據九十三年度「建築外殼隔熱性能檢測標準化之研究」、九十四年度「單一建材隔熱性能資料庫之建立」、「熱環境實驗室性能評估與CNLA 認證之建立」以及九十五年度「建築節能法令之建材熱傳與光學性能標準之研究」等計畫之研究成果，內政部建築研究所業已完成建築外殼隔熱性能檢測、隔熱膜熱傳導係數與玻璃光學性能之量測裝置與標準程序，使得性能實驗中心熱環境實驗室取得 TAF 量測實驗室之認證。不僅對於「建築節約能源設計技術規範與實例」中之各式建材隔熱性能表格內之數據提出修訂與建議，對於我國在推行「綠建築標章」之日常節能指標具有相當的貢獻度。並且配合中華建築中心綠建材專案小組完成「高性能節能玻璃綠建材解說與評估」之訂定。

綜合上述研究計畫成果，熱環境實驗室在玻璃建材之光學性質與熱學性質方面已具備單層平板玻璃、膠合玻璃與複層玻璃之量測能力；同時亦具有利用 WINDOW 5.2 程式將單層平板玻璃與空氣層組合成各式複層玻璃，並求出其光學與熱學性能之研發能力。

再者，在96年度之研究計畫成果中，研究團隊發現影響膠合與複層玻璃之光學性質之主要參數為膠膜；而此類玻璃，無論是直接塗覆在玻璃表面的 Low-E 玻璃或是夾在兩層玻璃之間的膠膜均是關鍵。而且對於

複層玻璃而言，中間隔熱膜性能（如圖 1-1 所示）以及複層玻璃密封性對於遮蔽係數（SC 值）之影響甚大。故對於本年度研究計畫之研究主題將訂定為節能玻璃遮陽性能之耐候特性探討。因此，計畫研究目標為完成節能玻璃遮陽性能耐候特性之影響評估。

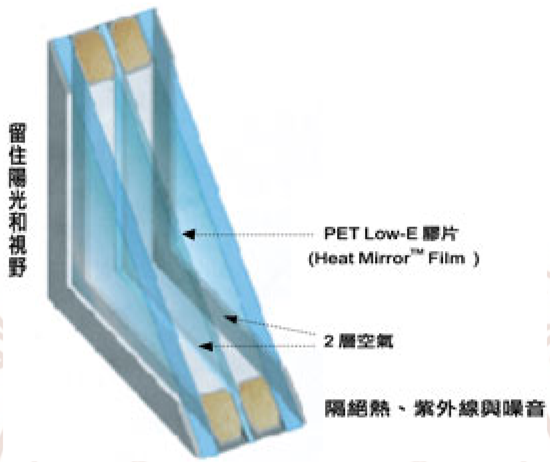


圖 1-1 三層節能玻璃之示意圖

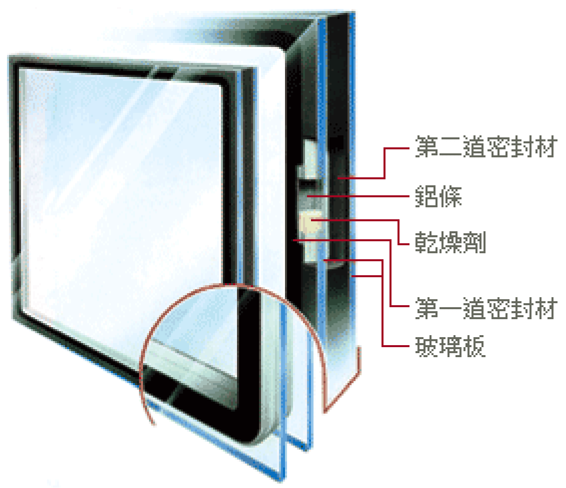


圖 1-2 複層玻璃示意圖

第二節 研究方法與內容

本年度研究計畫之研究內容主要為節能玻璃耐候特性實驗與節能玻璃遮陽性能實驗兩部分。其研究方法與內容分述如下：

(1) 節能玻璃耐候特性實驗

本年度計畫之首要工作乃經由節能玻璃耐候特性量測標準之比較分析明瞭節能玻璃之隔熱膜與塑膠密封材質量測技術與量測步驟，再利用性能實驗中心再生實驗室之 QUV 耐候試驗機進行節能玻璃耐候特性量測，藉以建立各項參數對節能玻璃建材耐候特性之影響。本研究計畫預計使用之 QUV 耐候試驗機可以再現陽光、雨水和露水所產生的破壞，通過將待測試材料放在經過控制的陽光和濕氣的交互循環中，同時提高溫度的方式來進行實驗。QUV 耐候試驗機採用紫外線 UV 燈管模擬陽光，同時通過冷凝或噴淋的方式模擬濕氣影響。QUV 耐候試驗機主要測試材料的粉化、開裂、脆化、強度下降、氧化等耐候性能，只需要幾天或幾周的時間，就可以再現戶外需要數月或數年所產生的破壞。本研究計畫將依照 ASTM G53-93、D4329-92、D4587-91 等標準先將目前市售七種 Low-E 節能玻璃（單層 Low-E 玻璃、Low-E 膠合玻璃（兩種）、Low-E 雙層玻璃（兩種）、Low-E 三層玻璃、單層 Low-E 奈米自潔淨玻璃等）裁切成儀器試件架之尺寸，放入 QUV 耐候試驗機進行實驗。實驗步驟如下所述：

(a) 裁切實驗試件與實驗前準備

(b) 將試驗試件於儀器試件架

(c) 進行第一循環實驗量測

(d) 更換試件位置，重複步驟 3 繼續進行實驗。

(e) 重複步驟 3~4，直到設定量測時間。

(2) 節能玻璃遮陽性能實驗

本研究計畫第二部分將經由 QUV 耐候試驗機實驗後之實驗試件，進行節能玻璃遮陽性能實驗。本研究計畫預計以熱環境實驗室之玻璃光學性質量測儀器分別量測待測試件之日光透射率／反射率、可見光透射率

／反射率、紫外光透射率／反射率以及遮蔽係數。藉此評估節能玻璃試件在各種暴露時間下之玻璃建材遮陽性能。有關節能玻璃遮陽性能實驗之儀器規格、量測程序以及光學性質之計算公式詳如 92~95 年度研究計畫報告。

第三節 研究流程與範圍

（1）研究流程

本計劃案之進行將採取國際標準探討與實驗印證兩種方式，其研究流程如圖 1-3 所示。主要工作內容如上節所述，首先是玻璃耐候性能之量測標準探討，在確認量測標準後，將進行玻璃耐候性能測試。由於玻璃耐候性能測試之測試時間冗長，因此為瞭解玻璃之耐候程度，在耐候性能測試進行一段時間後，將會先停止耐候試驗，而量測玻璃建材之光學性能以確認受測玻璃試件之光學性能是否已受氣候之影響而產生劣化。本研究計畫在耐候測試部分共有(1) 全尺度室外曝曬實驗、(2) 鉛筆硬度試驗、(3) 耐候性試驗、(4) 耐磨耗性試驗、(5) 耐酸性試驗、(6) 耐鹼性試驗、(7) 玻璃光照試驗等七項試驗項目。

(2) 研究範圍

本研究計畫之研究對象為節能玻璃，然而在本研究計畫中期望對於各種類玻璃建材能影響其耐候性能的因子能有全面性的探討，故本研究計畫所探討之對象並非只是符合高性能節能玻璃綠建材之玻璃建材，其他如單層玻璃、膠合玻璃以及反射玻璃等均在本研究計畫之探討範圍內。再者，根據過去研究計畫之研究成果，玻璃本身組成大部分為穩定的二氧化矽，氣候條件並不會影響其物性與化性；故本研究計畫對於常被使用之單層玻璃將不進行單獨探討其耐候性。而隔熱膜、表面塗附層、膠合玻璃中間膠膜以及密封膠等則是會受到氣候條件之影響，因此，針對含有此三因素之玻璃建材均涵蓋在本研究計畫中。是故，本研究計畫中所指之節能玻璃是泛指單層清玻璃除外之玻璃建材，其包含單層 Low-E 玻璃、半反射玻璃、膠合玻璃以及複層玻璃。

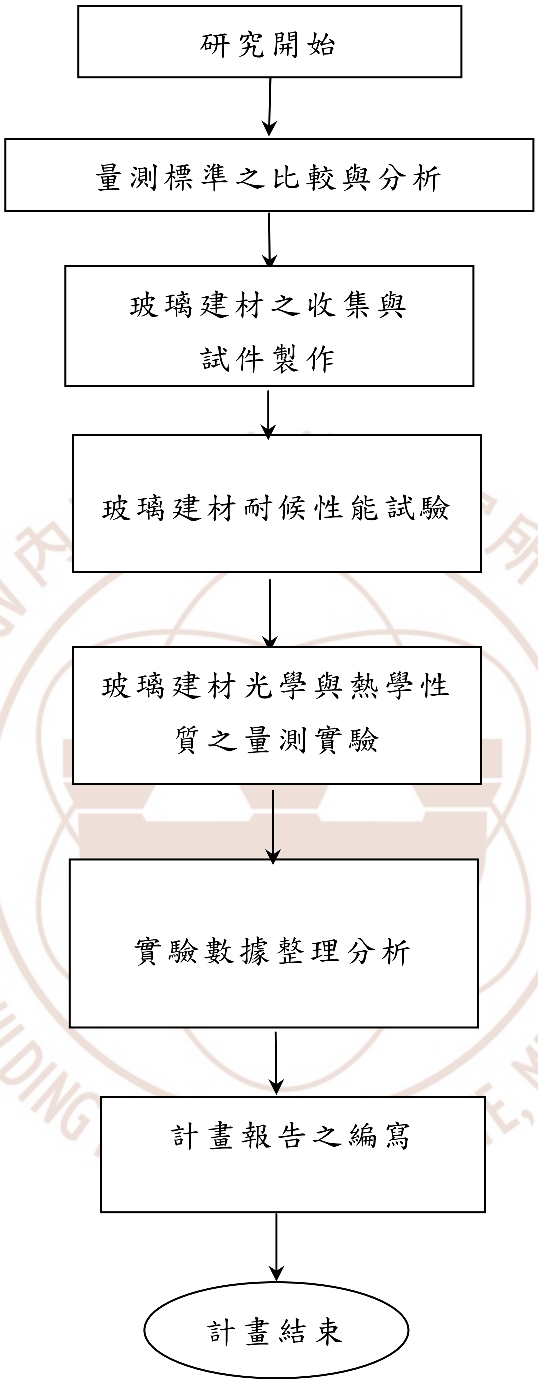


圖 1-3 研究計畫流程圖

(資料來源： 本研究整理)

第二章 玻璃建材之耐候特性探討

本年度之研究主題為玻璃建材在遮陽性能中之耐候性能探討，因此在本研究計畫首先針對各種玻璃建材中會對於耐候性能有影響的因子進行探討。

第一節 複層玻璃

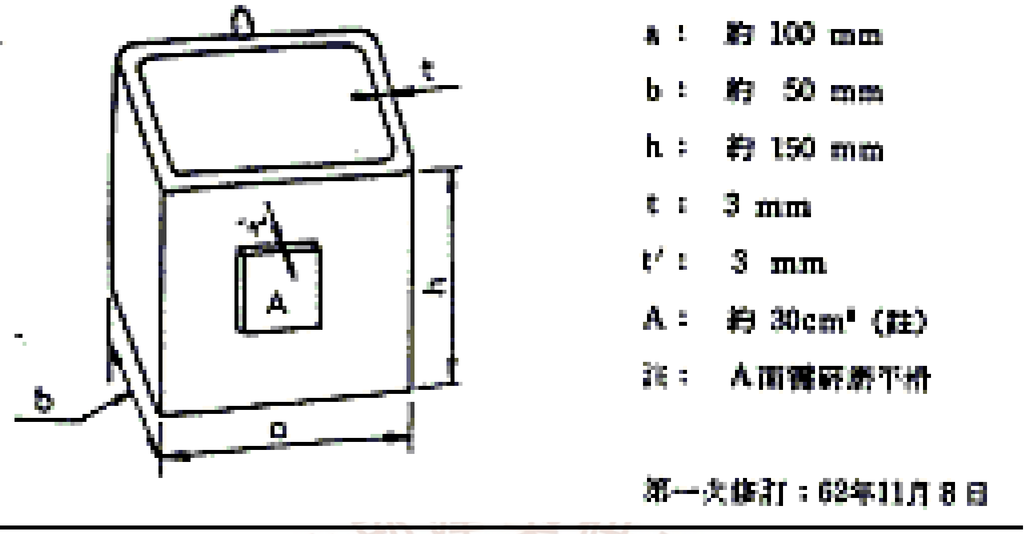
複層玻璃一般泛指雙層玻璃，所謂雙層玻璃在「CNS 2541 R2052：雙層玻璃」中定義為將兩片玻璃以一定之間隔，用以金屬或其他材料焊接封閉其四邊，對其中間空隙注入純淨之乾燥空氣而製成者。在CNS 2541 中所列出的玻璃厚度相當少，如表 2-1 所示，而且規定兩片玻璃之厚度差以 2mm以下為原則，而空氣層的厚度也僅規定 6mm與 12mm。有關雙層玻璃的試驗法CNS 2541 列出外觀試驗與露點試驗兩種。

在外觀試驗中規定以在雙層玻璃之正面 1 公尺之距離處以目視檢查之。而露點試驗是使用圖 2-1 之設備將雙層玻璃垂直置於設備測定位置，使注入丙酮容器之A面緊貼雙層玻璃，然後一面攪拌丙酮，一面加入乾冰之小片使其逐漸冷卻。於接觸容器雙層玻璃之內面，以聚光燈自反對側面觀察。以其內面開始發生水珠時之液溫為露點。至於雙層玻璃之露點溫度CNS 2541 並未規定，大部分廠商要求之露點溫度大都低於-35℃；亦即在-35℃的溫度下，雙層玻璃還沒有結露現象產生。

表 2-1 CNS 2541 定義之雙層玻璃組成

材料玻璃	厚度(mm)	適用之中國國家標準
普通平板玻璃	3,5,6	CNS 823 （普通平板玻璃）
浮式及磨光平板玻璃	3,5,6	CNS 2442 （浮式及磨光平板玻璃）

（資料來源：CNS 2541）



（資料來源：CNS 2541）

圖 2-1 CNS 2541 露點測試設備

從 CNS 2541 R2052 標準中並未對於雙層玻璃的耐候性能加以規定，因此本研究計畫將依據現今雙層玻璃常用之製造工法與材料進行探討。圖 2-2 為一般雙層玻璃之組成。兩片玻璃是以鋁條固定，並在鋁條中間填塞乾燥劑以防止水氣進入雙層玻璃之中間空氣層，另外有兩道密封材隔絕空氣與水氣進入中間空氣層。

目前在市場中流通的複層玻璃產品中，有使用單道密封和雙道密封材兩種。單道密封是指在複層玻璃側邊的密封上僅用一種外密封膠－聚硫膠或矽酮結構膠。而雙道密封是指在複層玻璃側邊的密封上第一道使用丁基密封膠，在外層第二道使用聚硫膠或矽酮結構膠。由於丁基密封膠的氣密性非常強，對惰性氣體和水分子的密封能力亦相當好，其密封能力分別是聚硫膠的 30 倍、矽酮結構膠的 60 倍。所以一般使用雙道密封的複層玻璃，其氣密性很好，產品幾乎宣稱可二十年不會有氣體進入其中。

矽酮結構膠具有抗紫外線與抗老化能力等耐候特性；其抗張拉力較強且具有較高的伸長率。而聚硫膠基本上不抗紫外線，亦即聚硫膠經長期紫外線照射，會出現老化和龜裂現象，因而喪失密封性，致使外界空氣進入複層玻璃內而影響其遮陽性能。再者，聚硫膠之抗張拉力、伸長率遠低於矽酮結構膠。所以，一般的隱框或半隱框玻璃必須使用矽酮結構膠，而明框玻璃則可使用聚硫膠。聚硫膠的特性如下表所示。

表 2-2 聚硫膠 (polysulfide) 之特性

用途	以聚硫膠為化學基礎的雙劑型，高彈性，不含溶劑的密封膠，可當做第密封膠使用
顏色	灰白（基本劑）黑色（固化劑），灰黑色 (混合後)
混合配比	重量配比 100:10, 體積配比: 100:11.5
混合密度	約 1.7 g/ml
邵氏 A 硬度	40 (室溫下 1-6 小時後) 55 (室溫下 14 天後) 德國標準 DIN 53505
拉力強度(24 小時後，溫度 23℃下)	0.45 MPa (25% 拉長), 0.70 Mpa (50% 拉長)
黏接性能	與玻璃，鋁金屬框及鍍鋅鋼材等的黏接性能極佳
使用溫度	室溫約 20℃不得低於 15℃，溫度升高將小/降低則延長使用溫度
操作時間	10-60 分鐘 (Gelnorm-測試法), (室溫約 23℃，密封膠溫度約 30℃)
運輸與儲存	非危險物品，在室溫不超過 25℃時可保存 6 個月

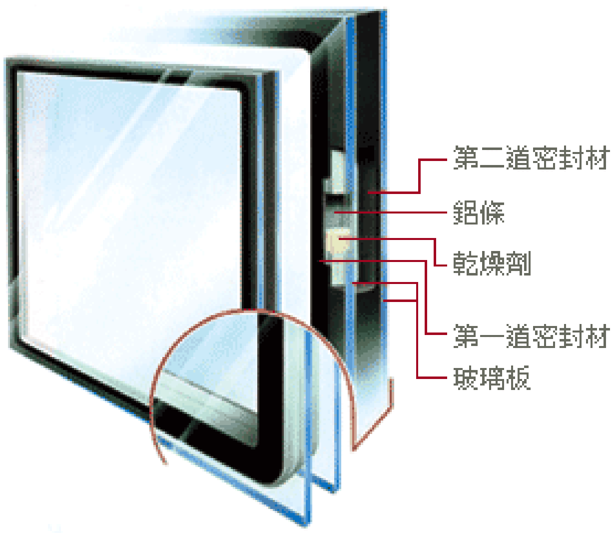
（資料來源：本研究整理）

另外，常用在第二道密封材料之丁基膠不會直接與外界空氣接觸，其特性如下表所示。

表 2-3 丁基膠之特性

用途	條狀丁烯膠是一種以聚異丁烯為化學基礎的單劑型，熱塑性，不含溶劑的密封膠. 可當做複層玻璃的密封膠使用 (無核心條狀丁烯膠)，同時亦可當做膠合玻璃的封邊膠 (有核心條狀丁烯膠) 與液態丙酸聚合樹脂一併用於安全玻璃窗的生產
黏接性能	與玻璃，鋁框，不銹鋼及鍍鋅鋼材等材料的黏接性能極佳
水蒸汽擴散性能	在密封膠厚度: 1mm 約 0.1 g/m2/d, DIN 53122 (23℃ / RH 85%)
剪力	在密封膠厚度 0.5mm 約 0.2 Mpa, 溫度 23℃ (拉伸速度: 100 mm/min)
密度	約 1.1 g/ml
儲存	在正常狀況下至少可保存 2 年
顏色	黑色

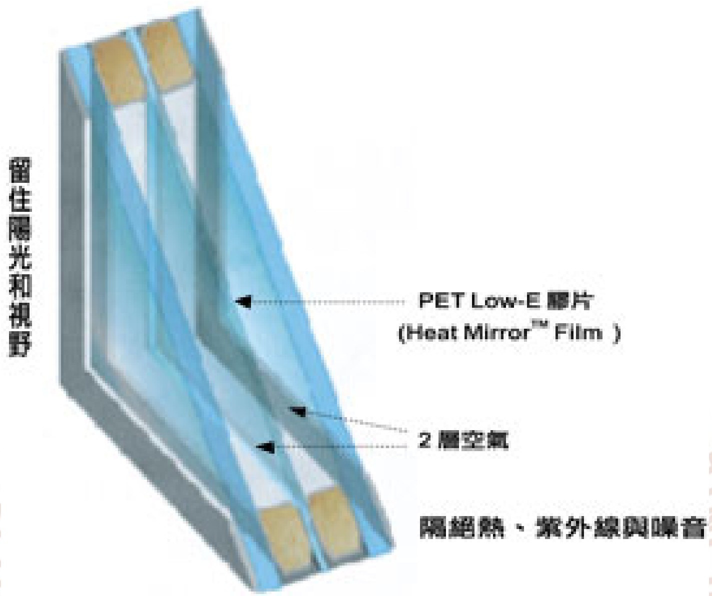
（資料來源：本研究整理）



（資料來源：台灣玻璃公司）

圖 2-2 雙層玻璃示意圖

除了雙層玻璃外，目前市面上亦出現在雙層玻璃中間加裝隔熱膜的三層玻璃，其示意圖如圖 2-3 所示。



（資料來源：光體玻璃公司）

圖 2-3 三層玻璃之示意圖

此種三層玻璃利用雙層玻璃中間空氣層加入 PET 隔熱膜之用意在於將進入玻璃的熱量吸收於隔熱膜中，阻隔太陽輻射熱量直接進入室內。不過根據前期研究計畫之研究結果顯示，隔熱膜之隔熱特性以及耐候性會是此類玻璃遮陽性能之主要影響因素。

第二節 膠合玻璃

在 CNS 1183 R2042：膠合玻璃標準中定義膠合玻璃係指板玻璃兩層或以上，用有色或無色透明中間膜膠合而成，供建築、鐵道車輛及船舶等窗門之有色或無色膠合玻璃。CNS 1183 並規定膠合玻璃在受外力而破損時，因為有中間膠膜之故，大部分的破片不致飛散。

膠合玻璃可依照形狀、耐衝擊性及耐貫穿性分類如下：

一、依形狀之種類：

(1) 平面膠合玻璃

(2) 曲面膠合玻璃

二、依耐衝擊性及耐貫穿性之分類為 I 類與 III 類，詳細特性如表 2-4 所示。

表 2-4 膠合玻璃之分類

種 類	記 號	特 性
I 類	L I	平面膠合玻璃及曲面膠合玻璃符合 CNS 1183 R2042 中第 3.5 節耐衝擊性規定者
III 類	L III	由 2 塊材料板玻璃製成，其總厚度 16mm 以下之平面膠合玻璃，符合 CNS 1183 R2042 中第 3.5 節耐衝擊性與第 3.5 節耐貫穿性規定者

（資料來源：CNS 1183）

而在膠合玻璃的品質部分，CNS 1183 列出有六項之特性，分別為外觀、翹曲、耐光性、耐沸水性、耐衝擊性與耐貫穿性。其中會與耐候特性有關連之特性為外觀與耐光性。外觀部分之檢測是依照 CNS 1184 R3043：膠合玻璃檢驗法進行。在 CNS 1184 第 3.1 節外觀檢查中規定，膠合玻璃的外觀是從測試試件正面約 50 公分距離處以目視進行檢查，有關外觀之規定如表 2-5 所示。

表 2-5 膠合玻璃之外觀規定

項　　目	品　　　質
氣泡	中間膜之氣泡，不得有能識別出來者，但不妨礙使用部分除外。
雜物	中間膜之雜物，不得有妨礙使用者。
重疊不齊	不妨礙使用者。
裂紋	不得有。
殘缺	長或寬在總厚度範圍以內者。
模糊暗影及磨傷	不妨礙使用者。

（資料來源：CNS 1183）

在耐光性規定部分，係指取三塊膠合玻璃試件，依照 CNS 1184 R3043：膠合玻璃檢驗法進行檢測。其規定結果為不得有顯著之變色及會妨礙使用之氣泡及混濁產生。又在使用使用無色透明中間膜之膠合玻璃之透光衰減率須在 10%以下。在 CNS 1184 第 3.4 節耐光性試驗中規定，膠合玻璃依照 CNS 10986：汽車用安全玻璃檢驗法試驗其可見光穿透率，並依照下列公式計算透光衰減率(l)。並檢查紫外線照射後之膠合玻璃是否有無變色、中間膜起泡或混濁等缺陷。

$$l\ (\%) = (a - b)/a \times 100$$

其中，a 為紫外線照射前之可見光透過率(%)。

B 則為紫外線照射後之可見光透過率(%)。

圖 2-4 與圖 2-5 為透明與彩色膠合玻璃之示意圖。從膠合玻璃示意圖可知，中間膜是膠合玻璃在使用期限內造成外觀以及耐光性產生老化，進而影響遮陽性能之主要對象。另外，根據本研究團隊與國內玻璃業者之訪談結果顯示，目前國

內亦有在膠合玻璃中間加入隔熱膜之節能膠合玻璃應用於建築物上。因此，由上述 CNS 1183 膠合玻璃之定義與 CNS 1184 膠合玻璃檢驗法可知膠合玻璃遮陽特性的耐候特性取決於中間 PVB 膜以及膠膜本身的耐候特性與光學性質。

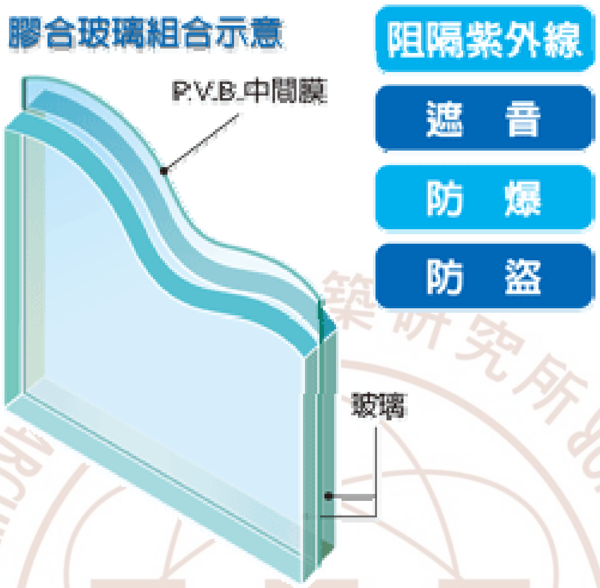


圖 2-4 透明膠合玻璃示意圖

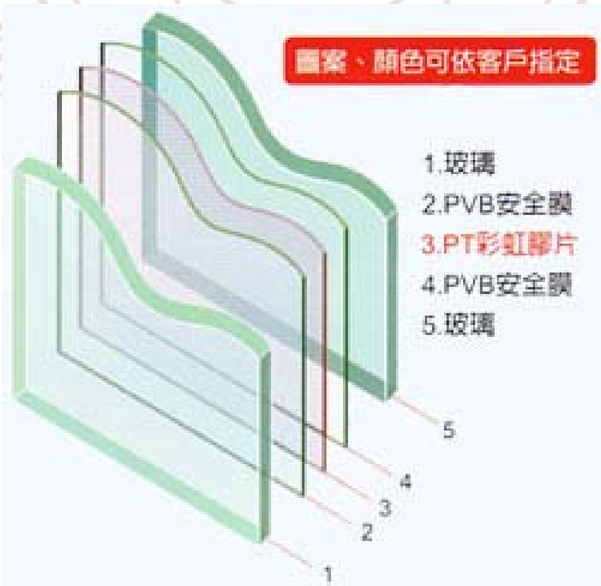


圖 2-5 彩色膠合玻璃示意圖

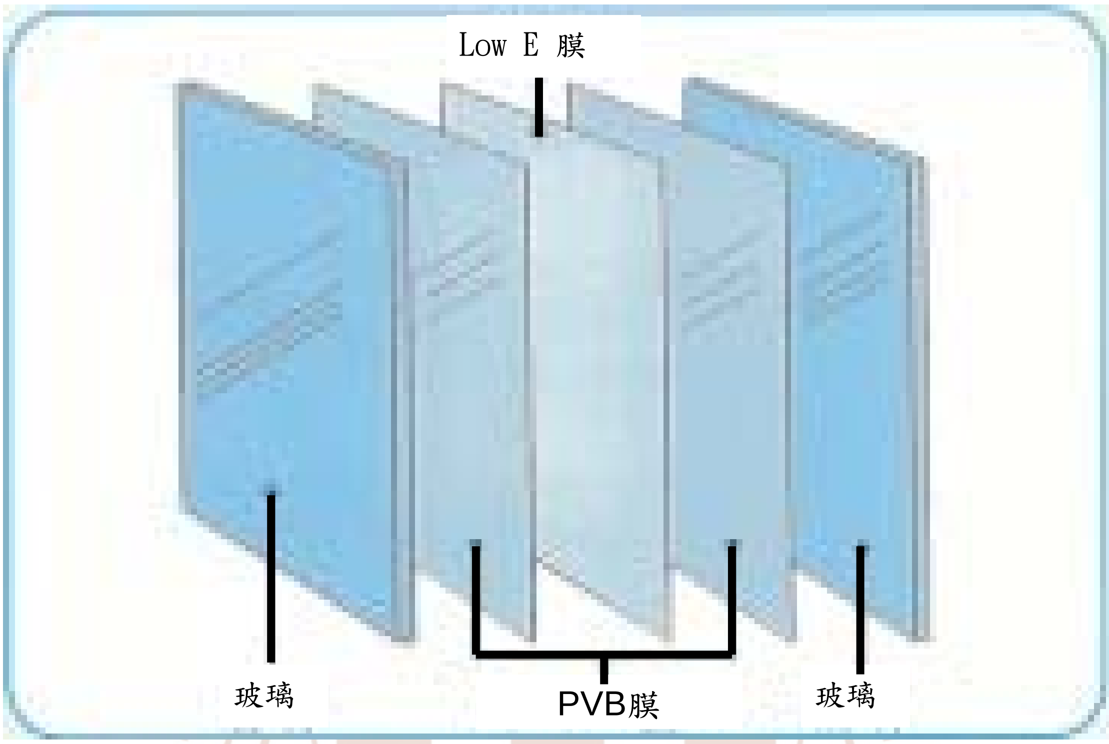


圖 2-6 膠合玻璃加隔熱膜之示意圖

第三節 低輻射 Low-E 玻璃

目前在玻璃建材應用於建築物上，低輻射Low-E玻璃常被視為節能玻璃的代表。所謂低輻射Low-E玻璃是在玻璃表面以真空濺鍍或化學沈積等技術塗覆一層薄的金屬層。此金屬層的功用為反射及吸收入射的太陽輻射熱能，而阻擋太陽輻射熱能進入室內。低輻射Low-E玻璃的金屬層中的鍍銀層對紅外線光具高反射功能，而鍍銀層下之底層鍍膜通常為二氧化錫(SnO_2)抗反射鍍膜，其用以增加玻璃的透光率。

一般而言低輻射 Low-E 玻璃可區分為 Hard Low-E 與 Soft Low-E 兩種。所謂的 Hard Low-E 玻璃是直接將 Low-E 薄膜濺鍍在平板玻璃上再用固化程序使得 Hard Low-E 玻璃之表面具有抗老化特性，其示意圖如圖 2-7 所示。而 Soft Low-E 玻璃與 Hard Low-E 玻璃之差別在於 Soft Low-E 玻璃的鍍膜層並未再處理固化程序，所以通常是應用於雙層中空玻璃上。目前國內台灣玻璃公司所生產之低輻射

Low-E 玻璃即為 Soft Low-E 玻璃。Soft Low-E 玻璃的示意圖如圖 2-8 所示。圖 2-9 為各種低輻射 Low-E 玻璃與平板玻璃之比較光譜圖。由圖可知，Low-E 鍍膜對波長 380nm 至 780nm 的可見光波段有著高透視率，不致因玻璃對可視光的高反射率而產生嚴重的反眩光公害。但是對紅外線光有較高之反射率(波長 780~2500nm)。

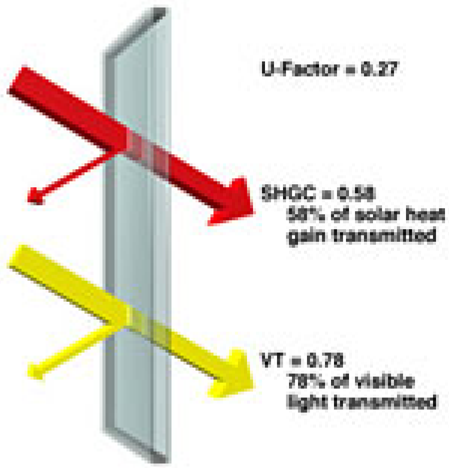


圖 2-7 Hard Low-E 玻璃示意圖

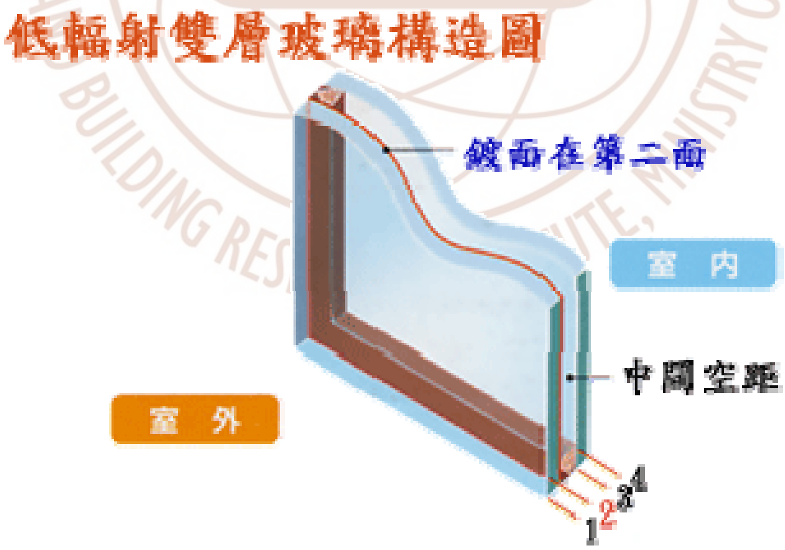


圖 2-8 Soft Low-E 雙層玻璃示意圖

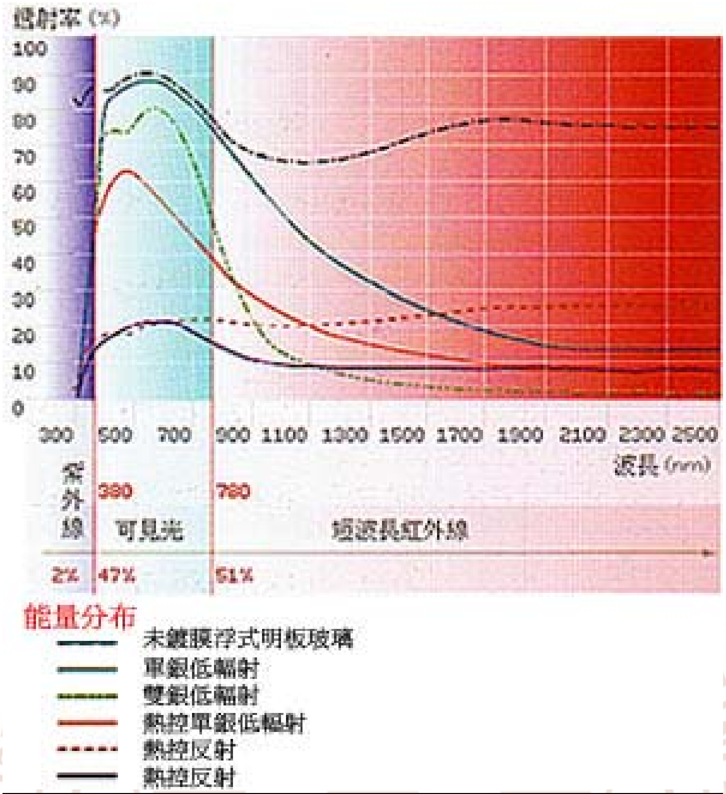


圖 2-9 Low-E 雙層玻璃之光譜特性

目前 CNS 並無低輻射 Low-E 玻璃之相關標準，而本研究計畫在此參考 CNS 13032 R2197：日射熱反射玻璃中之相關規定與 CNS 13033 R3176：日射熱反射玻璃檢驗法之檢驗程序作為低輻射 Low-E 玻璃在耐候特性之依據。在 CNS 13032 中規定日射熱反射玻璃係指以遮斷日射熱為主要目的，在玻璃表面敷施具有熱反射性薄膜之玻璃。但不含將具有反射性之合成樹脂薄膜接著於玻璃上者。而在與玻璃耐候特性上之規定 CNS 13032 規定有耐光性、耐磨耗性、耐酸性與耐鹼性等四種。有關耐光性、耐磨耗性、耐酸性與耐鹼性之規定分述如下：

(1) 耐光性：日射熱反射玻璃之耐光性係依 CNS 13033 所規定之耐光性試驗，可見光透過率差之絕對值需為 4%以下。

(2) 耐磨耗性：日射熱反射玻璃之耐磨耗性係依 CNS 13033 所規定之耐磨耗性試驗，可見光透過率差之絕對值需為 4%以下。

(3) 耐酸性：日射熱反射玻璃之耐酸性係依 CNS 13033 所規定之耐酸性試驗，可見光透過率差之絕對值需為 4%以下。

(4) 耐鹼性：日射熱反射玻璃之耐鹼性係依 CNS 13033 所規定之耐鹼性試驗，可見光透過率差之絕對值需為 4%以下。

至於 CNS 13033 R3176 檢驗法中有關耐光性、耐磨耗性、耐酸性與耐鹼性之檢驗法敘述如下：

■ **耐光性試驗：**

(1) 試體：與製品同一方法製成約 50 x 100mm 之試片作為試體。

(2) 裝置：使用 CNS 10986 （汽車用安全玻璃檢驗法）所規定之紫外線照射裝置。

(3) 試驗程序：

(a) 試體用附有積分球之色差計，附積分球之分光測光器或具有與其同等性能之計測器求出可見光透過率(%)。

(b) 在保持於 45±5℃之(2)裝置中，將試體向著光源放置於離光源約 230mm 處。

(c) 以紫外線照射試體 1000 小時。

(d) 就紫外線照射後之試體用(a) 之計測器求出可見光透過率(%)。

(e) 求出(a) 之值與(d) 的差值之絕對值。

■ **耐磨耗性試驗：**

(1) 試體：與製品同一方法製成約 100 x 100mm 之試片作為試體。

(2) 磨耗試驗機：磨耗試驗機使用提巴(Taper) 式磨耗試驗機或與其同等以上性能者。圖 2-9 之磨耗試驗機係以 65±10rpm 之速度旋轉之水平旋轉台及以 65±3mm 間隔固定的圓滑旋轉的一對磨耗輪所構成。

(a) 旋轉台：旋轉台係以水平在同一平面旋轉，各磨耗輪施於試體之載重為 4.9N。

(b) 磨耗輪：磨耗輪為直徑 45~50mm，厚度 12.5mm，混入研磨材之中硬度橡膠製，而安裝成無軸向之搖桿及旋轉振動者，型別為 Taper 式之 No. CS-10F。

(3) 試驗程序：

(a) 磨耗前試體用附有積分球之色差計，附積分球之分光測光器或具有與其同等性能之計測器求出圖 2-10〝○〞記號所示之 1 點之可見光透過率(%)。

(b) 試體敷施薄膜面為磨耗面設置於磨耗試驗機之旋轉台上，使試體旋轉磨耗，此時之回轉次數若為 A 類則是 200 次，若為 B 類則是 100 次。

(c) 磨耗後試體用計測器求出圖 2-10〝X〞記號所示之 4 點之可見光透過率(%)。

(d) 求出(a) 之值與(c) 的差值之絕對值。

■ **耐酸性試驗：**

(1) 試體：與製品同一方法製成約 25 x 50mm 之試片作為試體。

(2) 試驗步驟：

(a) 浸漬前試體用附有積分球之色差計，附積分球之分光測光器或具有與其同等性能之計測器求出可見光透過率(%)。

(b) 將試體整個浸漬於溫度 23±2℃之 1N 氫氯酸中，浸漬時間若為 A 類則是 24 小時，若為 B 類則是 6 小時。

(c) 浸漬後水洗、乾燥之試體，用計測器求出可見光透過率(%)。

(d) 求出(a) 之值與(c) 的差值之絕對值。

■ **耐鹼性試驗：**

(1) 試體：與製品同一方法製成約 25 x 50mm 之試片作為試體。

(2) 試驗程序：

(a) 浸漬前試體用附有積分球之色差計，附積分球之分光測光器或具有與其同等性能之計測器求出可見光透過率(%)。

(b) 將試體整個浸漬於溫度 23±2℃之 1N 氫氧化鈉中，浸漬時間若為 A 類則是 24 小時，若為 B 類則是 6 小時。

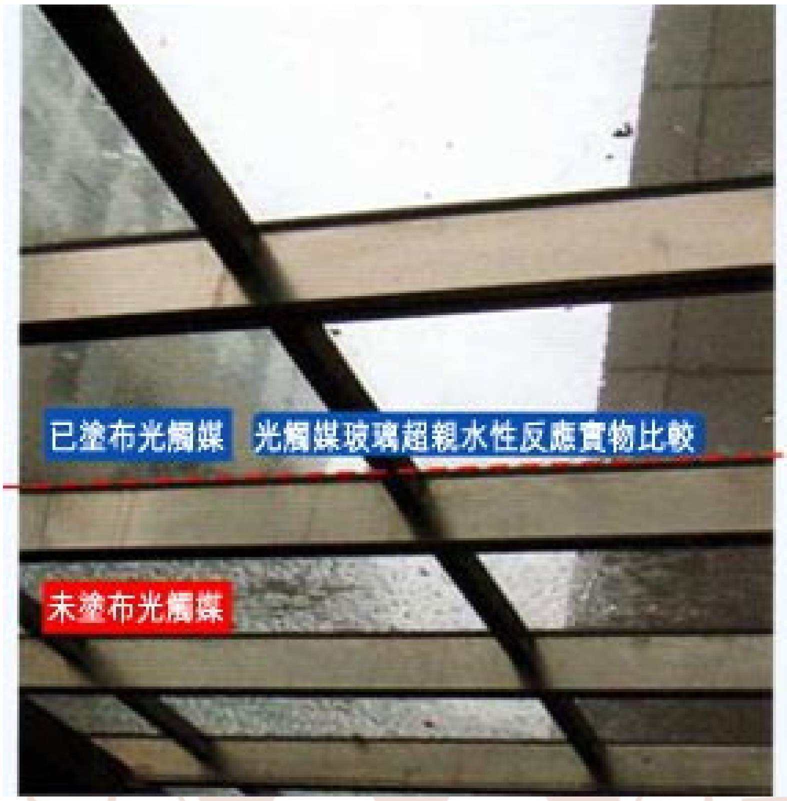
(c) 浸漬後水洗、乾燥之試體，用計測器求出可見光透過率(%)。

(d) 求出(a) 之值與(c) 的差值之絕對值。

第四節 光觸媒玻璃

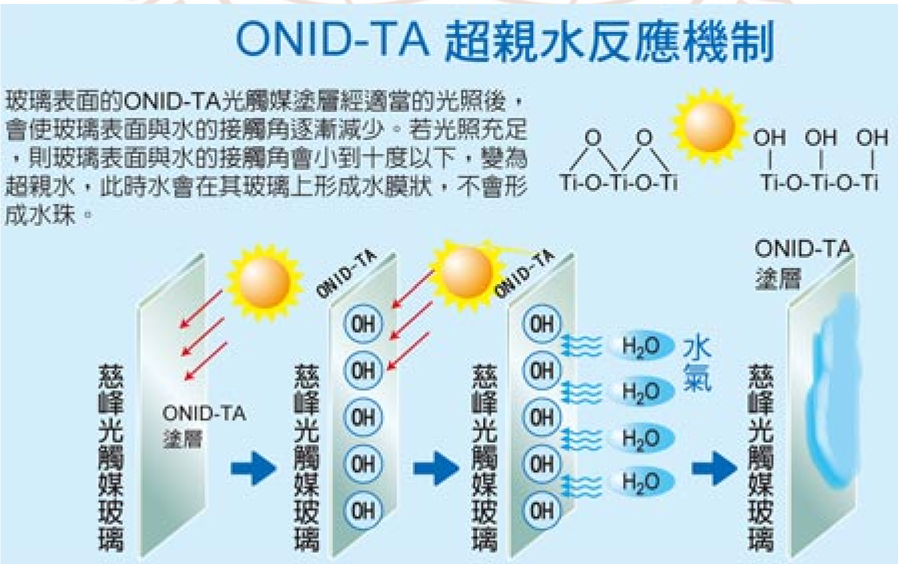
本研究計畫除了對於傳統常用的玻璃建材進行耐候特性之研究，另外對於比較特殊應用的光觸媒玻璃亦納入探討。光觸媒玻璃是指披覆有光觸媒的玻璃建材。其光觸媒可藉由濺鍍(Sputterlng)，化學蒸鍍(CVD)。物理蒸鍍(PVD)，或以擦塗、滾塗、浸塗、噴塗、刷塗等方式加到玻璃表面，並經高溫固化燒結，可與任何市面上加工的玻璃建材產品如強化玻璃、膠合玻璃、複層玻璃搭配應用。光觸媒玻璃具有抗污、易潔、空氣淨化以及抑菌防霉之特性。由圖 2-10 可知，光觸媒玻璃因為其親水性可使得雨水在玻璃表面上形成水膜而不會形成水珠，因此其抗污及自潔淨效果均較一般玻璃好，而使得外界環境污染物不易附著且會隨著雨水而被沖刷。

由於目前 CNS 以及 ISO 等國內外標準並未有相關光觸媒玻璃的標準與檢測方法，但因為光觸媒玻璃亦是將光觸媒塗覆在玻璃表面，與 Low-E 玻璃製作程序相似。故本研究計畫僅由台灣光觸媒協會之相關資料以及 CNS 13033 R3176：日射熱反射玻璃檢驗法之檢驗程序作為光觸媒玻璃在耐候特性檢測上之依據。在光觸媒玻璃之耐候特性檢測部分，本研究計畫提出除了上述低輻射 Low-E 玻璃之耐光性、耐磨性以及耐酸鹼性試驗外，亦需針對親水性與光觸媒塗層附著力試驗等進行規範。有關親水性與光觸媒塗層附著力試驗之規定目前尚無相關之測試方法與規範。



(資料來源： 泉耀科技股份有限公司)

圖 2-10 光觸媒玻璃示意圖



(資料來源： 慈峰玻璃公司)

圖 2-11 光觸媒玻璃之親水反應機制

第三章 玻璃耐候特性試驗

第一節 全尺度戶外曝曬實驗

依據 ASTM G7-97 : Standard Practice for Atmospheric Environmental Exposure Testing of Nonmetallic Materials 之規範進行玻璃試件戶外曝曬實驗。全尺度戶外曝曬實驗之目的在於實際將玻璃試件置於戶外經由長時間的曝曬獲得玻璃建材之遮陽性能受外界環境影響的相關資訊。

本研究計畫共選定單層 Hard Low-E、光觸媒單層光玻璃、6mm 綠＋6mm 光膠合玻璃、6mm 綠＋中間隔熱膜＋6mm 光膠合玻璃、6mm 綠＋12mm 空氣層＋6mm 光複層玻璃（使用結構密封膠）、6mm 綠＋12mm 空氣層＋6mm 光複層玻璃（使用矽力康密封膠）以及 6mm 綠＋12mm 空氣層＋隔熱膜＋12mm 空氣層＋6mm 光複層玻璃等七種種類玻璃進行全尺度戶外曝曬實驗。選定單層 Hard Low-E 以及光觸媒單層光玻璃兩種單層玻璃之目的在於探討 Hard Low-E 膜以及光觸媒塗膜受外界環境之影響程度。選定 6mm 綠＋6mm 光膠合玻璃、6mm 綠＋中間隔熱膜＋6mm 光膠合玻璃兩種膠合玻璃之目的在於探討 PVB 膜以及中間隔熱膜受外界環境之影響程度。而選定 6mm 綠＋12mm 空氣層＋6mm 光複層玻璃（使用結構密封膠）、6mm 綠＋12mm 空氣層＋6mm 光複層玻璃（使用矽力康密封膠）之目的在於探討不同密封膠對外界環境之影響程度。對於 Soft Low-E 雙層玻璃而言，其耐候性能乃是取決於其外層密封膠的耐候性能。若外層密封膠因受外界環境影響而劣化將導致 Soft Low-E 雙層玻璃內的 Soft Low-E 塗附層氧化，故此乃選用兩種不同密封膠進行測試之另一原因。

圖 3-1 與圖 3-2 分別為使用結構膠與矽力康作為密封膠之複層玻璃。

全尺度戶外曝曬實驗之實驗流程是首先量測待測試件之光學性質，接著放置戶外進行曝曬，曝曬週期為一個月，然後再量測待測試件之光學性質並比較試驗前後之光學性質。

表 3-1 為全尺度戶外曝曬實驗前試件之光學性質。表 3-2 為全尺度戶外曝曬實驗兩個月後試件之光學性質。表 3-3 為全尺度戶外曝曬實驗六個月後

試件之光學性質。實驗結果顯示，在全尺度實驗六個月後之光學性質並未有差異。但是在外觀觀察方面，光觸媒單層光玻璃之表面潔淨度較其他未塗覆光觸媒之玻璃佳。然而，因為量測實驗中必須將玻璃試件表面清潔後再進行量測，故所量得的光學性質亦是與未實驗前相同。

至於密封膠對於玻璃耐候性之影響部分，目前六個月的實驗期間並未使矽力康密封膠出現老化而有外界空氣洩漏進入複層玻璃中間空氣層的現象產生。另外，在膠合玻璃中間夾隔熱膜之試件中，吾人發現在曝曬後會產生小氣泡，如圖 3-3 所示。此試件產生的氣泡確實會影響日後玻璃之遮陽性能。

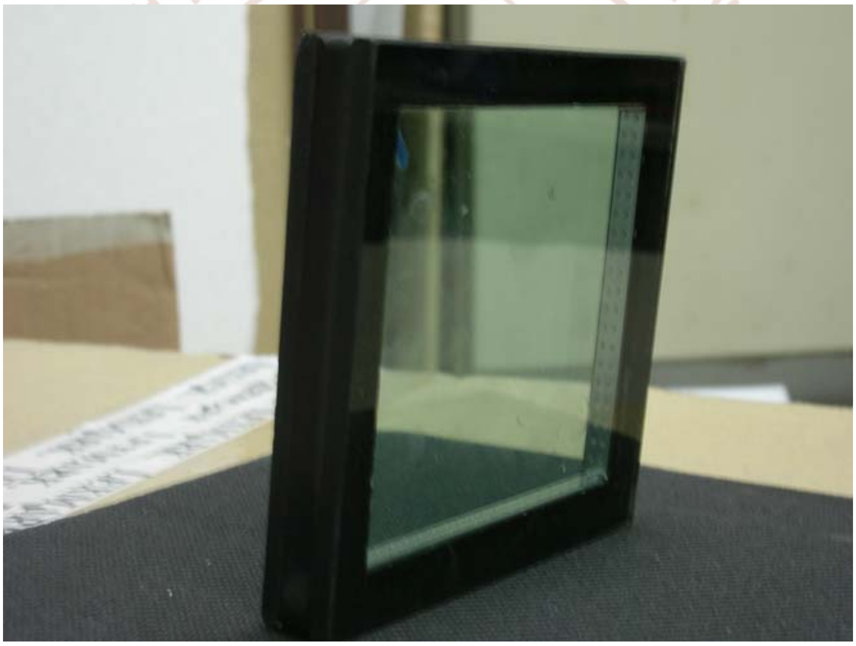


圖 3-1 複層玻璃（使用結構膠）

（資料來源：本研究整理）

圖 3-2 複層玻璃（使用矽力康密封膠）

（資料來源：本研究整理）

圖 3-3 中間夾隔熱膜之膠合玻璃受熱之質變

表 3-1 全尺度戶外曝曬實驗前試件之光學性質

	可見光透過率 (%)	可見光反射率 (%)	太陽熱能透過率 (%)	太陽熱能反射率 (%)	紫外線透過率 (%)
單層 Hard Low-E	68	9	54	10	37
光觸媒單層光玻璃	88	9	78	8	52
6mm 綠＋6mm 光膠合玻璃	71	7	39	6	<1
6mm 綠＋中間隔熱膜＋6mm 光膠合玻璃	53	7	28	6	＜1
6mm 綠＋12mm 空氣層＋6mm 光複層玻璃（使用結構密封膠）	65	12	35	6	13
6mm 綠＋12mm 空氣層＋6mm 光複層玻璃（使用矽力康密封膠）	65	12	35	6	13
6mm 光＋12mm 空氣層＋隔熱膜＋12mm 空氣層＋6mm 光複層玻璃	60	22	23	36	<1

量測日期：97/04/20

（資料來源：本研究整理）

表 3-2 全尺度戶外曝曬實驗中試件之光學性質

	可見光透過率(%)	可見光反射率(%)	太陽熱能透過率(%)	太陽熱能反射率(%)	紫外線透過率(%)
單層 Hard Low-E	68	9	54	10	37
光觸媒單層光玻璃	88	9	78	8	52
6mm 綠＋6mm 光膠合玻璃	71	7	39	6	<1
6mm 綠＋中間隔熱膜＋6mm 光膠合玻璃	53	7	28	6	＜1
6mm 綠＋12mm 空氣層＋6mm 光複層玻璃（使用結構密封膠）	65	12	35	6	13
6mm 綠＋12mm 空氣層＋6mm 光複層玻璃（使用矽力康密封膠）	65	12	35	6	13
6mm 光＋12mm 空氣層＋隔熱膜＋12mm 空氣層＋6mm 光複層玻璃	60	22	23	36	<1

量測日期：97/06/22

（資料來源：本研究整理）

表 3-3 全尺度戶外曝曬實驗後試件之光學性質

	可見光透過率 (%)	可見光反射率 (%)	太陽熱能透過率 (%)	太陽熱能反射率 (%)	紫外線透過率 (%)
單層 Hard Low-E	68	9	54	10	37
光觸媒單層光玻璃	88	9	78	8	52
6mm 綠＋6mm 光膠合玻璃	71	7	39	6	<1
6mm 綠＋中間隔熱膜＋6mm 光膠合玻璃	52	7	28	6	＜1
6mm 綠＋12mm 空氣層＋6mm 光複層玻璃（使用結構密封膠）	64	12	35	6	13
6mm 綠＋12mm 空氣層＋6mm 光複層玻璃（使用矽力康密封膠）	65	12	35	6	13
6mm 光＋12mm 空氣層＋隔熱膜＋12mm 空氣層＋6mm 光複層玻璃	59	22	23	36	<1

量測日期：97/10/22

（資料來源：本研究整理）

第二節 耐磨耗性與耐酸鹼性實驗

本研究計畫除了測試上述 CNS 標準中規定的耐磨耗性與耐酸鹼性外，在期初報告中審查委員曾提及是否可將 Low-E 膜或隔熱膜直接貼於戶外，就不會有將熱集中於玻璃內部的問題；再者，目前日本亦有直接將 Low-E 膜置於戶外之實際應用。然而，隔熱膜或 Low-E 膜直接貼在玻璃室外側之唯一問題點在於隔熱膜或 Low-E 膜若沒有經過固化處理，則其表面硬度將是會直接影響此種玻璃建材之遮陽性能。故本研究計畫依據 CNS 10757 K6801：塗料一般檢驗法(有關塗膜之物理、化學抗性之試驗法)之規定中有關表面硬度試驗選取單層 Hard Low-E 玻璃、隔熱膜＋單層玻璃以及光觸媒玻璃三種進行表面硬度測試。有關 CNS 10757 K6801：塗料一般檢驗法(有關塗膜之物理、化學抗性之試驗法)之規定如下所述：

硬度(鉛筆法)：鉛筆硬度值試驗機法及手劃法兩種。本研究計畫以鉛筆硬度值試驗機法作為測試基準。

■ 試驗機法：

(1) 概要:使用鉛筆硬度值試驗機試驗塗膜之硬度，並以鉛筆之硬度號數表示之方法。

(2) 裝置及材料:

(a) 試驗用鉛筆:符合 CNS 552[鉛筆]所規定且適合於塗膜硬度測定用者。鉛筆之硬度以硬度號數為 9H 者為最硬，6B 者為最軟，較硬者為上位。鉛筆應先僅除外覆木質部分使筆芯露出約 3mm 支圓柱形，其次置於堅硬且平坦平面上之砂紙上，以筆芯垂直抵住砂紙邊描繪圓圈之方式，徐徐研磨之，使其前端成平坦且邊角銳利。

備考：本試驗所用之鉛筆，經有關機關依不同濃度號數之批次實施檢查，並選取一系列之濃度號數組待用。

(b) 砂紙：CNS 1074[砂紙]所規定之 400 號砂紙

(c) 試驗板：尺度為 150*70*0.8mm 之鋼板。

(d) 橡皮擦：CNS 7753[橡皮擦]所規定者。

(3) 試片之製作：

依 CNS 9007[塗料一班檢測法(取樣及試片處理部分)]第 3.3 節之規定，以試樣之產品標準所規定之方法，塗於一片試驗板之單面上，經乾燥後，至於室內約 1 小時以上即可供為試驗用之試片。

(4) 操作：

(a) 將試片塗面朝上水平安裝於塗膜用鉛筆硬度值試驗機之試片安裝台上。

(b) 將鉛筆安裝於鉛筆夾座使鉛筆之筆芯尖端觸及通過試驗機重錘重心之垂直線與塗面交點。

(c) 其次，以平衡重錘調整至施加於試片之鉛筆載重達平衡為止，鎖緊固定螺栓並自塗面取下鉛筆，固定支桿置放 1.00(+-)0.5kg 之重錘於重錘台上，鬆弛固定螺絲，將鉛筆筆芯前端觸及塗面，使重錘之載重施加於其前端上。

(d) 以定速迴轉把手，將試片與筆芯相反方向水平移動約 3mm 刮搔塗面，其移動速度應為 0.5mm。挪移試片使與移動方向垂直，變換位置刮搔 5 次，惟每次刮搔所用筆芯尖端均應先行重加研磨後，方可供用。

(e) 以塗膜破損作評定，如於 5 次刮搔中，塗膜之破損未深達試驗板之基材達兩次時，應更換硬度號數大 1 號之鉛筆並做同樣之試驗。如此試驗以選取塗膜破損次數達 2 次以上之鉛筆，並記錄該鉛筆硬度號數小 1 號之號數。

(f) 以塗膜刮傷作評定，如 5 次刮搔實驗中，塗膜受刮傷(2)不滿兩次時，應更換硬度號數大 1 號之鉛筆並做同樣試驗。如此試驗以選取塗膜刮傷次數達 2 次以上之鉛筆，並記錄該鉛筆硬度號數小 1 號之號數。

註(2):塗膜刮傷之認定乃以塗膜表面之稍微刮入之傷痕為準，至於受壓時將陷入之凹痕則不計。判別時，應先以橡皮擦將試驗部位之碳粉以不傷及塗膜之條件下，小心擦拭之。在字與刮搔方

向垂直之方向，言試片塗膜面 45 度角目是觀測之，如有可看出之傷痕及視為[刮傷]。

(5) 評定：

(a) 以塗膜破損狀態評定時，以硬度號數相鄰之二支鉛筆，求取塗膜破損為兩次以上及未滿兩次之 1 組，並以未滿兩次之鉛筆硬度號數，作為塗膜之鉛筆刮搔值。

(b) 以塗膜刮傷狀態評價時，以硬度號數相鄰之二支鉛筆，求取塗膜刮傷為二次以上及未滿兩次之 1 組，並以未滿兩次之鉛筆硬度號數，作為塗膜之鉛筆刮搔值。

單層 Hard Low-E 玻璃、隔熱膜＋單層玻璃以及光觸媒玻璃三種進行表面硬度測試之結果如下表所示。由鉛筆硬度試驗結果可知單層 Hard Low-E 玻璃與光觸媒玻璃兩種玻璃的測驗硬度值均符合要求值：≥8H，而對於隔熱膜直接貼覆在單層玻璃的測驗硬度值則為 F 不符合要求值：≥8H。試驗結果代表單層 Hard Low-E 玻璃與光觸媒玻璃的硬度大於鉛筆之最硬硬度：9H。此乃因為單層 Hard Low-E 玻璃與光觸媒玻璃在表面有經過固化過程處理，而隔熱膜直接貼覆在單層玻璃上則是因沒有固化過程處理而使得量測到的硬度其實為隔熱膜本身的硬度。故將隔熱膜直接貼覆在玻璃並暴露在室外面的作法必會影響其耐久性，進而致使其遮陽性能在長時間使用時衰減。

表 3-4 鍍膜鉛筆硬度測試結果

玻璃種類	試驗項目與方法	試驗結果	要求值
單層 Hard Low-E 玻璃	CNS 10757(1995) 鍍膜鉛筆硬度	>9H	≥8H
隔熱膜＋單層玻璃	CNS 10757(1995) 鍍膜鉛筆硬度	F	≥8H
光觸媒玻璃	CNS 10757(1995) 鍍膜鉛筆硬度	>9H	≥8H

（資料來源：本研究整理）

表 3-5 為光觸媒玻璃進行耐磨耗性試驗、耐酸性試驗與耐鹼性試驗三種測試之結果。表中之測試結果顯示光觸媒玻璃在經過 500g，200 轉的耐磨耗性試驗後其試驗前後的可見光透過率差絕對值為 0.09%小於 CNS 13032 要求值 4%甚多，其光學性能幾乎不受表面磨耗影響。此試驗值是因為光觸媒玻璃在經過表面固化處理後使得光觸媒塗層不受實際外界空氣之懸浮塵粒影響而刮傷玻璃表面。而在光觸媒玻璃之耐酸與耐鹼性試驗前後的可見光透過率差絕對值分別為為 0.8%與 1.14%，亦都小於 CNS 13032 要求值 4%。不過可看出光觸媒玻璃的耐酸鹼性對於其光學性能之影響高於耐磨耗性對其光學性能之影響。

表 3-5 光觸媒玻璃耐磨耗與耐酸鹼性測試結果

玻璃種類	試驗項目與方法	試驗結果	CNS 13032 (1992) 要求值
耐磨耗性試驗(%) (500g，200 轉，CS-10F)	CNS 13033 (1992)	0.09	可見光透過率差絕對值為 4%以下
耐酸性試驗(%) (1N HCl，24 小時)	CNS 13033 (1992)	0.8	可見光透過率差絕對值為 4%以下
耐鹼性試驗(%) (1N NaOH，24 小時)	CNS 13033 (1992)	1.14	可見光透過率差絕對值為 4%以下

（資料來源：本研究整理）

表 3-6 為 HardLow-E 玻璃進行耐磨耗性試驗、耐酸性試驗與耐鹼性試驗三種測試之結果。表中之測試結果顯示光觸媒玻璃在經過 500g，200 轉的耐磨耗性試驗後其試驗前後的可見光透過率差絕對值為 0.12%小於 CNS

13032 要求值 4%甚多，其光學性能幾乎不受表面磨耗影響。此試驗值是因為 HardLow-E 玻璃在經過表面固化處理後不受實際外界空氣之懸浮塵粒影響而刮傷玻璃表面。而在 HardLow-E 玻璃之耐酸與耐鹼性試驗前後的可見光透過率差絕對值分別為為 1.1%與 1.2%，亦都小於 CNS 13032 要求值 4%。

表 3-6 單層 Hard Low-E 玻璃耐磨耗與耐酸鹼性測試結果

玻璃種類	試驗項目與方法	試驗結果	CNS 13032 (1992) 要求值
耐磨耗性試驗(%) (500g，200 轉，CS-10F)	CNS 13033 (1992)	0.12	可見光透過率差絕對值為 4%以下
耐酸性試驗(%) (1N HCl，24 小時)	CNS 13033 (1992)	1.1	可見光透過率差絕對值為 4%以下
耐鹼性試驗(%) (1N NaOH，24 小時)	CNS 13033 (1992)	1.2	可見光透過率差絕對值為 4%以下

（資料來源：本研究整理）

表 3-7 為單層玻璃直接貼附隔熱膜進行耐磨耗性試驗、耐酸性試驗與耐鹼性試驗三種測試之結果。表中之測試結果顯示直接貼附隔熱膜的單層玻璃在經過 500g，200 轉的耐磨耗性試驗後其試驗前後的可見光透過率差絕對值為 6.31% 大於 CNS 13032 要求值 4%甚多，其光學性能會受表面磨耗有顯著地影響。此試驗值是因為隔熱膜的表面硬度不夠，因而當玻璃受實際外界空氣之懸浮塵粒影響時會刮傷玻璃表面。而在玻璃之耐酸與耐鹼性試驗前後的可見光透過率差絕對值分別為為 2.5%與 2.1%，小於 CNS 13032 要求值 4%。

表 3-7 隔熱膜＋單層玻璃耐磨耗與耐酸鹼性測試結果

玻璃種類	試驗項目與方法	試驗結果	CNS 13032 (1992) 要求值
耐磨耗性試驗(%) (500g，200 轉，CS-10F)	CNS 13033 (1992)	6.31	可見光透過率差絕對值為 4%以下
耐酸性試驗(%) (1N HCl，24 小時)	CNS 13033 (1992)	2.5	可見光透過率差絕對值為 4%以下
耐鹼性試驗(%) (1N NaOH，24 小時)	CNS 13033 (1992)	2.1	可見光透過率差絕對值為 4%以下

（資料來源：本研究整理）

第三節　玻璃光照試驗

為了進一步確認在戶外曝曬實驗中玻璃建材表面的溫度是否會對遮陽性能有所影響。本研究計畫以一模擬光源照射玻璃試件，藉此模擬當太陽光照射在玻璃上之情形。在光源方面本研究以氙氣短弧燈來模擬太陽光的照射，再以熱電偶測量室內外玻璃之表面溫度，最後經由紀錄器與電腦紀錄內外溫度的變化情形。圖 3-4 為模擬光源實驗示意圖與實際設備圖。表 3-8 為設備說明。

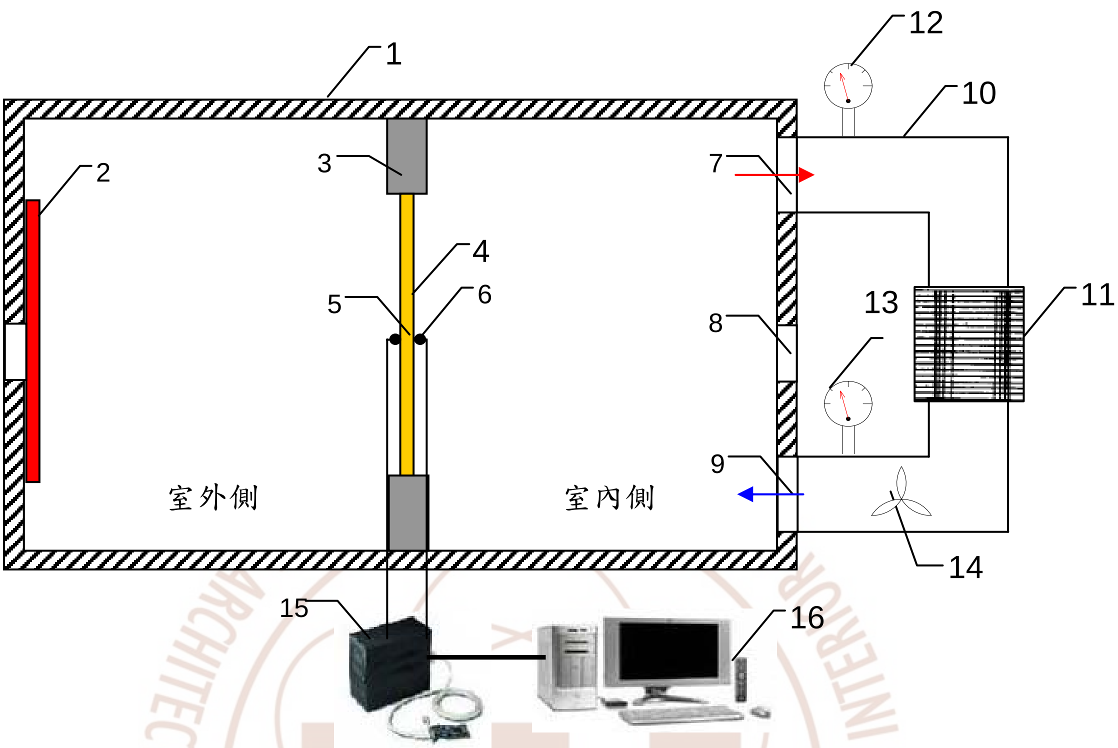


圖 3-4 模擬光源實驗儀器示意圖

(資料來源： 本研究整理)

表 3-8 光照實驗設備說明

項目	敘述	項目	敘述
1	設備外殼	9	送風口
2	日光模擬燈具	10	風管
3	試件固定座	11	冷卻系統
4	試件	12	回風溫度&風速測點
5	熱電偶	13	送風溫度&風速測點
6	熱電偶	14	進氣風扇
7	回風口	15	溫度自動記錄器
8	紅外線熱像儀拍攝窗口	16	溫度紀錄軟體與電腦

（資料來源 本研究整理）

本研究計畫目前共進行了單層 Hard low-E 玻璃、隔熱膜貼附 6mm 光玻璃、6mm Low-E＋6mm 光膠合玻璃、光觸媒 6mm 綠＋6mm 光膠合玻璃、6mm 綠＋12mm 空氣層＋6mm 光複層玻璃、6mm 綠＋12mm 空氣層＋隔熱膜＋12mm 空氣層＋6mm 光複層玻璃等六種玻璃之光照實驗，以探討各類玻璃在受光照射後之室內、外溫度變化情形。量測結果分別如下所述：

(1) 單層 Hard low-E 玻璃

單層 Hard Low-E 玻璃的電鍍面以及未電鍍面受到光照射之溫度分佈圖分別如圖 3-5 與 3-6 所示。由實驗結果可知，Low-E 膜會吸收太陽輻射並且反射一部份的太陽輻射能量。故當 Low-E 膜朝室外側時，室外側溫度會較室內側溫度高。室外側穩態的溫度約為 75℃、室內側穩態的溫度約為 72℃。而且因為是 6mm 單層玻璃，所以室內外側溫度差相當小。然而，對於目前傳統將 Low-E 膜朝室內側的情況，量測溫度卻是室內側溫度高於室外側溫度。這是因為 Low-E 膜吸收與反射的熱量僅能以傳導方式往室外側傳遞，而 Low-E 膜在室外側則是以傳導加上對流方式將熱量傳遞至戶外。所以在圖 3-6 中的室內側溫度（Low-E 膜側溫度）高達 85℃，比將 Low-E 膜朝室外側之穩態溫度高出 10℃。

室內玻璃表面溫度會對於室內人員之熱舒適性有極大的影響。Somsak Chaiyapinunt 等學者以曼谷的氣象條件探討清玻璃、反射玻璃、膠合玻璃、Low-E 低輻射玻璃以及雙層玻璃對於辦公大樓室內熱舒適性的影響。Somsak Chaiyapinunt 將 PPD(Predicted Percentage of Dissatisfied)定義區分為太陽輻射 PPD 與玻璃表面溫度 PPD 兩部分。太陽輻射 PPD 是指由太陽輻射直接穿透玻璃進入室內造成人員舒適性不滿意度，玻璃表面溫度 PPD 則是指玻璃表面溫度所造成的輻射熱對於人員舒適性不滿意度。由 Somsak Chaiyapinunt 等學者的研究結果顯示在大部分的玻璃中，太陽輻射 PPD 的值比玻璃表面溫度 PPD 的值高，如圖 3-7 所示。再者，對於隔熱膜貼附在玻璃上將會因為太陽輻射穿透率降低，而使得太陽輻射 PPD 的值降低；但是因為隔熱膜會增加玻璃的吸收率而使得玻璃表面溫度升高，而致使玻璃表面溫度 PPD 的值升高。

圖 3-8 與圖 3-94 為各種類型玻璃的太陽輻射穿透率以及吸收率與 PPD 之間的關係。由圖可知，太陽輻射穿透率與吸收率與 PPD 有線性關係。但是太陽輻射穿透率對 PPD 的影響較太陽輻射吸收率影響顯著。

因此，本研究計畫中對於 Low-E 玻璃電鍍膜置於室內側或室外側之探討可以由 Somsak Chaiyapinunt 等學者之研究獲得一致的結果。當 Low-E 電鍍面置於室外側時的室內玻璃表面溫度較 Low-E 電鍍面置於室內側時的室內玻璃表面溫度低，就會使得室內人員的熱舒適性提高，同時藉由熱傳導進入室內的熱量也會降低。

(2) 隔熱膜貼附 6mm 光玻璃

隔熱膜貼附 6mm 光玻璃受到光照射之溫度分佈圖分別如圖 3-10 所示。由實驗結果可知，隔熱膜貼附 6mm 光玻璃朝外時，因為隔熱膜會吸收與反射太陽輻射，所以室外側表面溫度約為 68℃，室內側表面溫度約為 67℃。此結果與 Low-E 膜在室外側的結果相符，而表面溫度之高低在於薄膜的反射率與吸收率。因此，進入室內的熱量是由隔熱膜的太陽輻射穿透率決定；而經由熱傳導進入室內的熱量則是由隔熱膜的吸收率決定。

(3) 6mm Low-E＋6mm 光膠合玻璃

6mm Low-E＋6mm 光膠合玻璃的量測溫度如圖 3-11 所示。當 Low-E 膜是在 PVB 膜內時，其室外側穩態溫度為 80℃、室外側穩態的溫度約為 78℃。此量測結果與圖 3-6 將 Low-E 膜朝室外側的結果相符合。因為在中間的 Low-E 膜吸收部分的熱量之後，會往室內與室外測傳導，而使室外側表面溫度高於室內側溫度。

(4) 光觸媒 6mm 綠＋6mm 光膠合玻璃

光觸媒 6mm 綠＋6mm 光膠合玻璃的量測溫度如圖 3-12 所示。其室外側穩態溫度為 80℃、室外側穩態的溫度約為 78℃。此量測結果與 6mm Low-E＋6mm 光膠合玻璃的量測溫度相符合。因此，對於膠合玻璃而言，光觸媒塗覆面以及 Low-E 電鍍面甚至中間的隔熱膜將是影響進入室內熱量的因素。

(5) 6mm 綠＋12mm 空氣層＋6mm 光複層玻璃

6mm 綠＋12mm 空氣層＋6mm 光複層玻璃的量測溫度如圖 3-13 所示。其室外側穩態溫度為 82℃、室內側穩態的溫度約為 72℃。室內外溫度差為 10℃。此溫度差是因為中間空氣層的隔絕效果，使得室內外溫度差比 Low-E 玻璃還大。故以 Somsak Chaiyapinunt 等學者的研究結果可知，使用雙層玻璃不僅可降低太陽輻射直接穿透能量，亦可因室內側玻璃溫度降低而使得在玻璃建材附近的熱舒適性滿意度減少。

(6) 6mm 綠＋12mm 空氣層＋隔熱膜＋12mm 空氣層＋6mm 光複層玻璃

6mm 綠＋12mm 空氣層＋隔熱膜＋12mm 空氣層＋6mm 光複層玻璃的量測溫度如圖 3-14 所示。其室外側穩態溫度為 80℃、室內側穩態的溫度約為 42℃。當增加隔熱膜於中間空氣層內，會因為隔熱膜吸收大量的熱量而使得室內外溫度差增大至 38℃。然而，Somsak Chaiyapinunt 在圖 3-9 的研究結果顯示雙層玻璃貼附隔熱膜的玻璃表面溫度 PPD 比其他種類的玻璃還高，但是量測結果卻是顯示出室內側表面溫度較雙層玻璃低。此差異在於本研究計畫的隔熱膜是置於雙層玻璃的中間，而圖 3-9 中的隔熱膜卻是貼附在室內側玻璃上面。故圖 3-9 的 double pane glass with film 的表面溫度一定較圖 3-14 的溫度高。

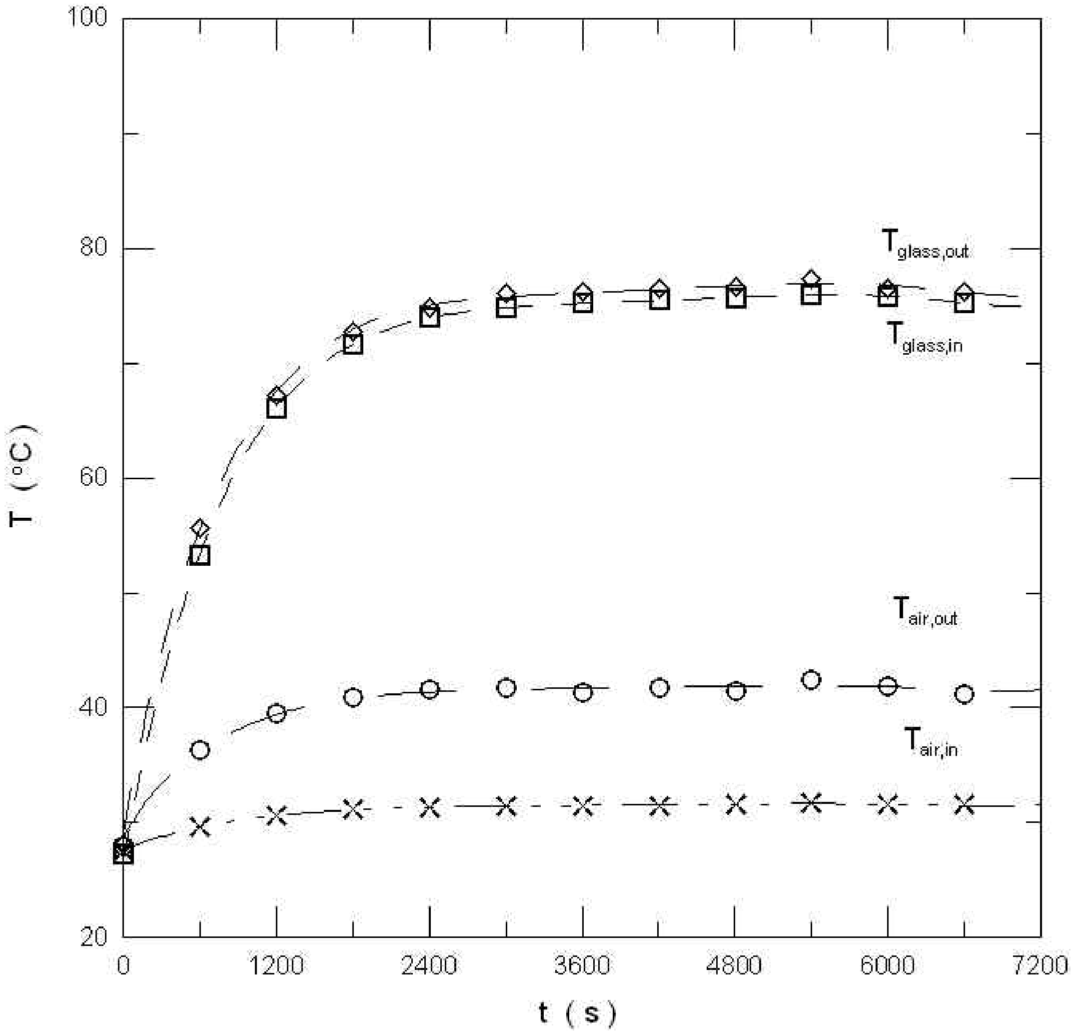


圖 3-5 單層 Hard low-E 玻璃電鍍面之溫度量測

(資料來源： 本研究整理)

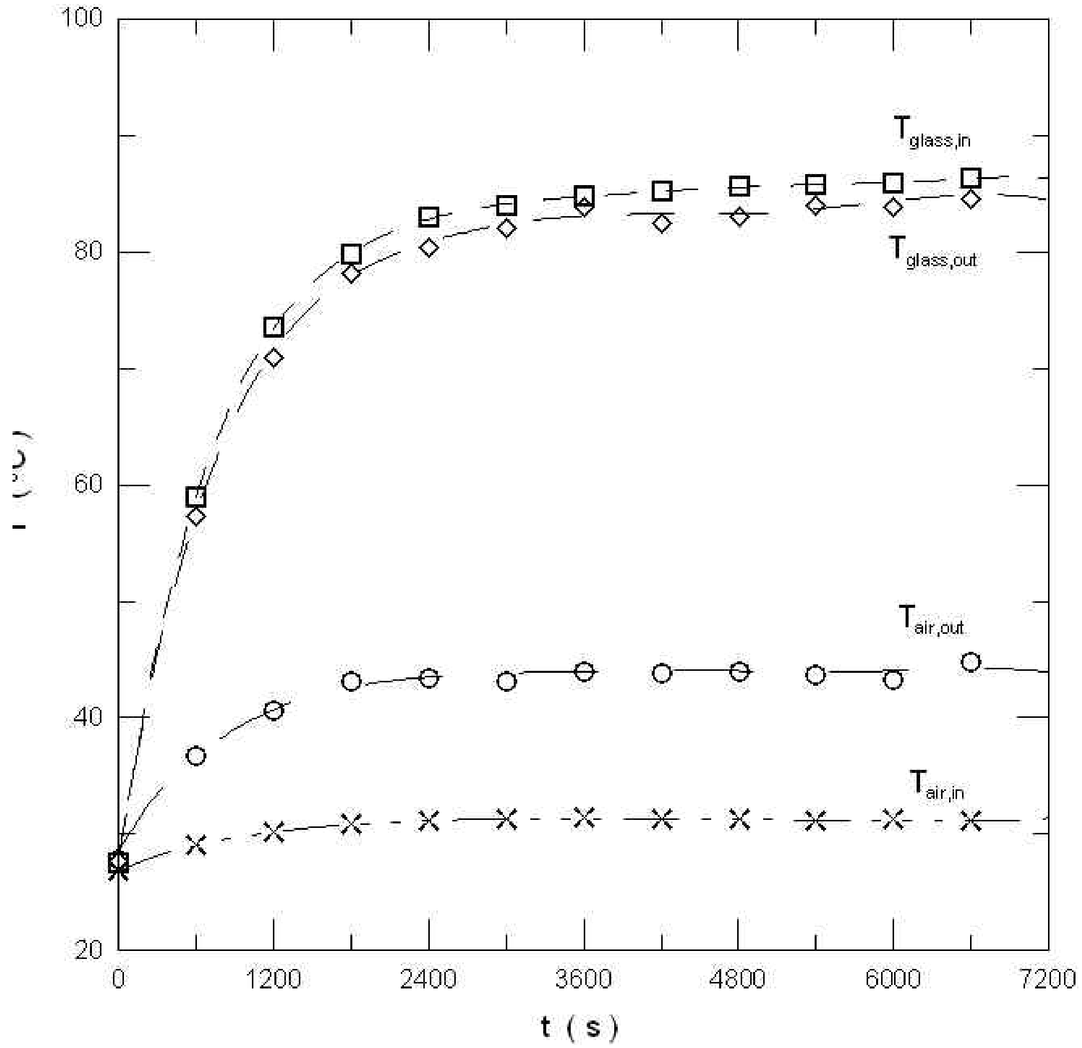


圖 3-6 單層 Hard low-E 玻璃未電鍍面之溫度量測

(資料來源： 本研究整理)

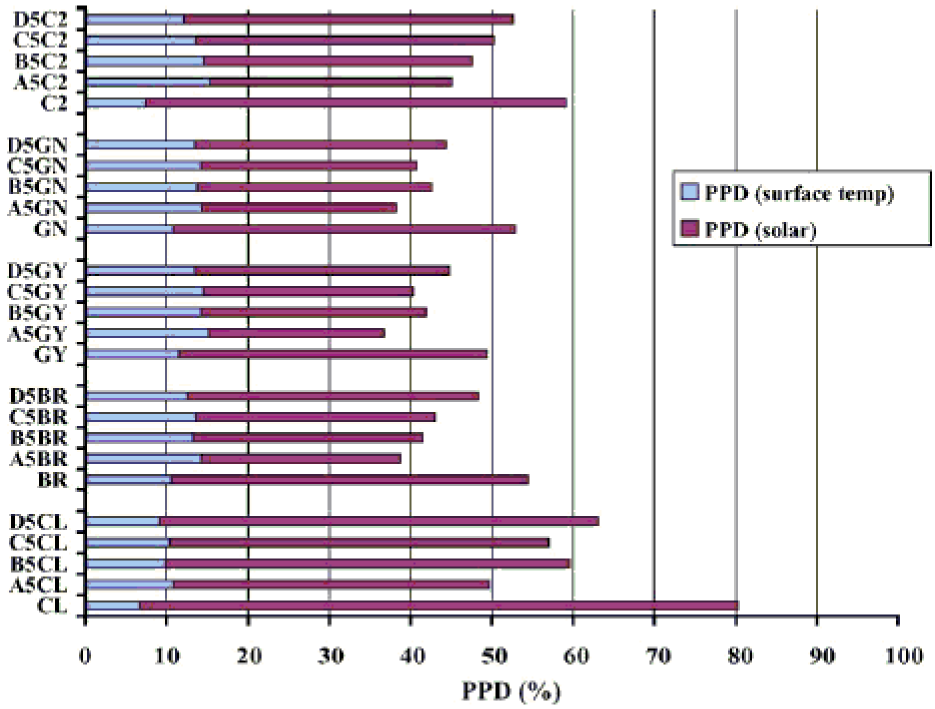


圖 3-7 玻璃種類對 PPD 的關係

(資料來源：參考書目[7])

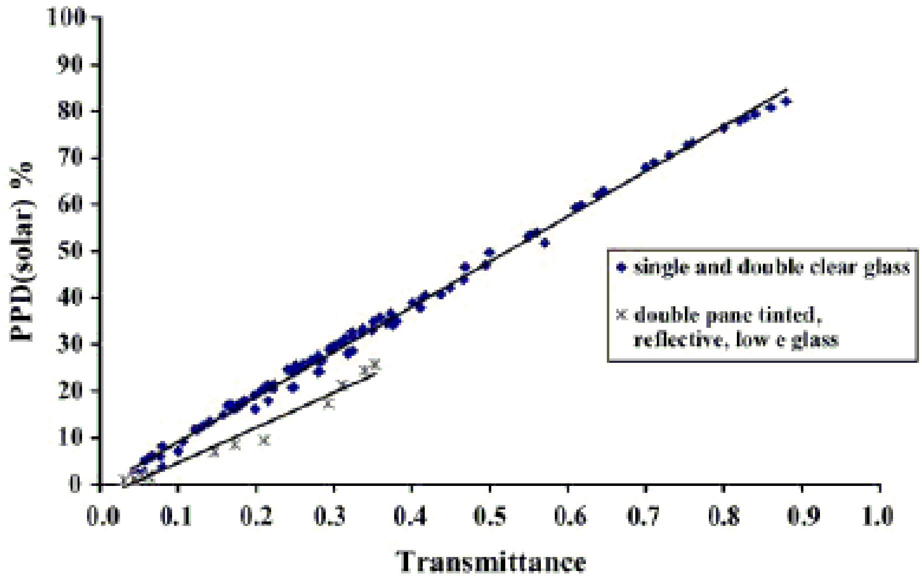


圖 3-8 玻璃穿透率對 PPD 的關係

(資料來源：參考書目[7])

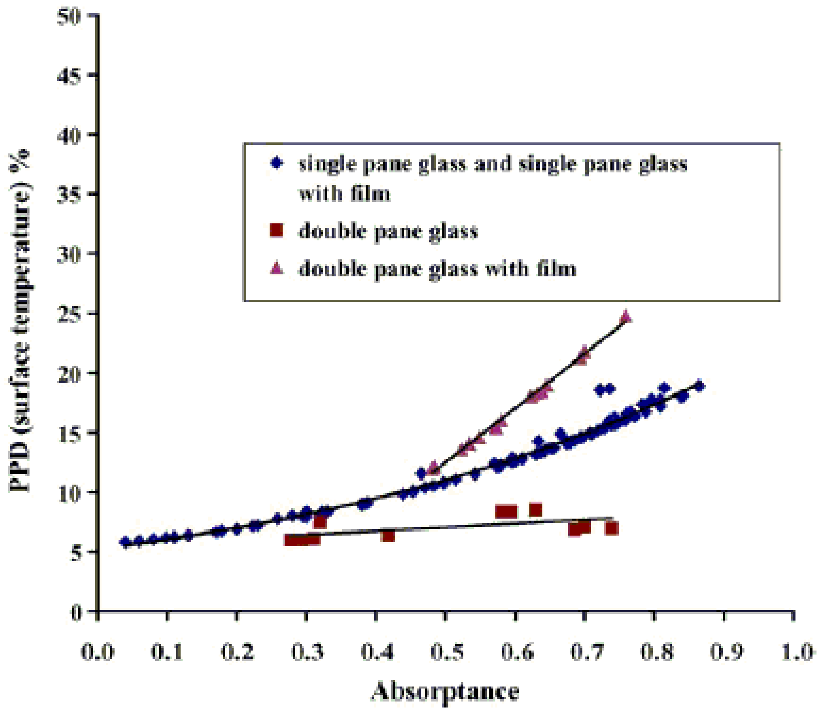


圖 3-9 玻璃吸收率對 PPD 的關係

(資料來源：參考書目[7])

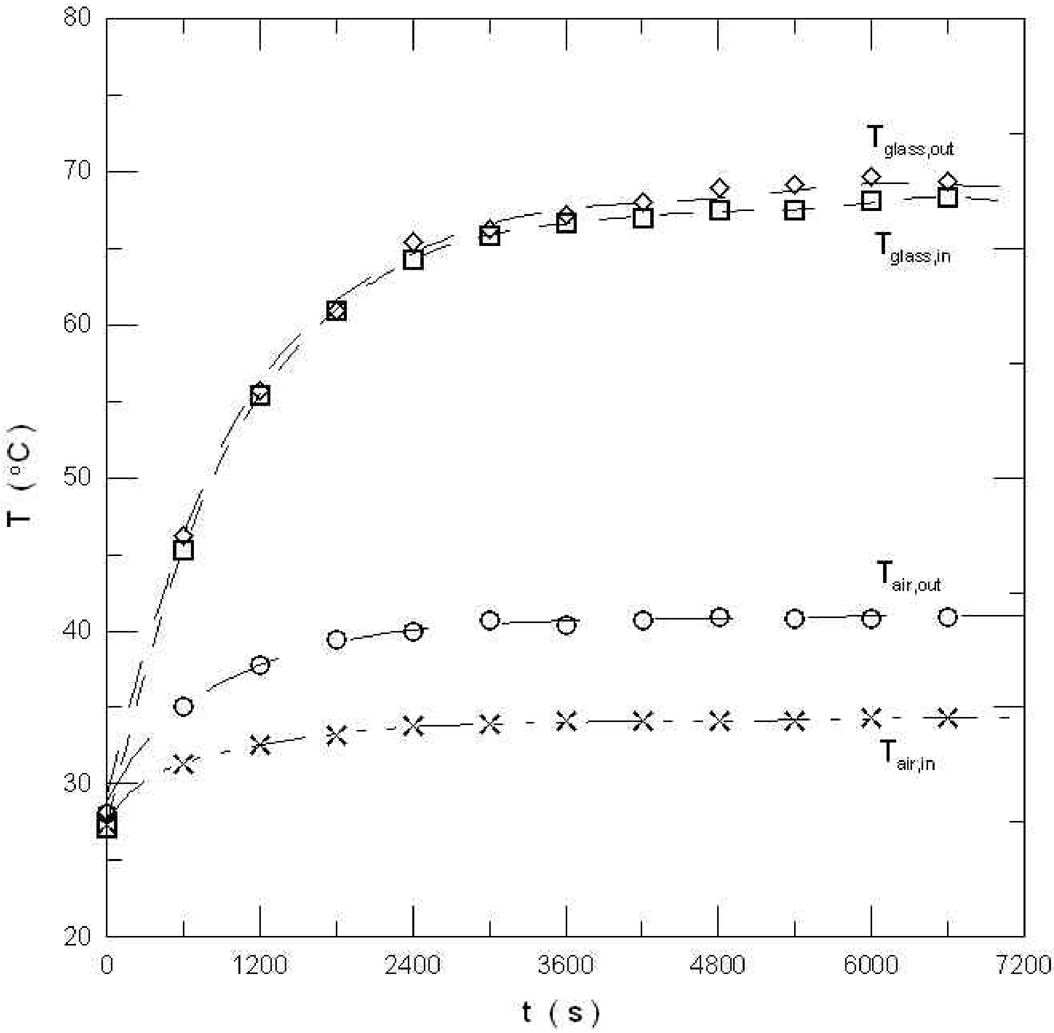


圖 3-10 隔熱膜貼附 6mm 光玻璃之溫度量測

(資料來源： 本研究整理)

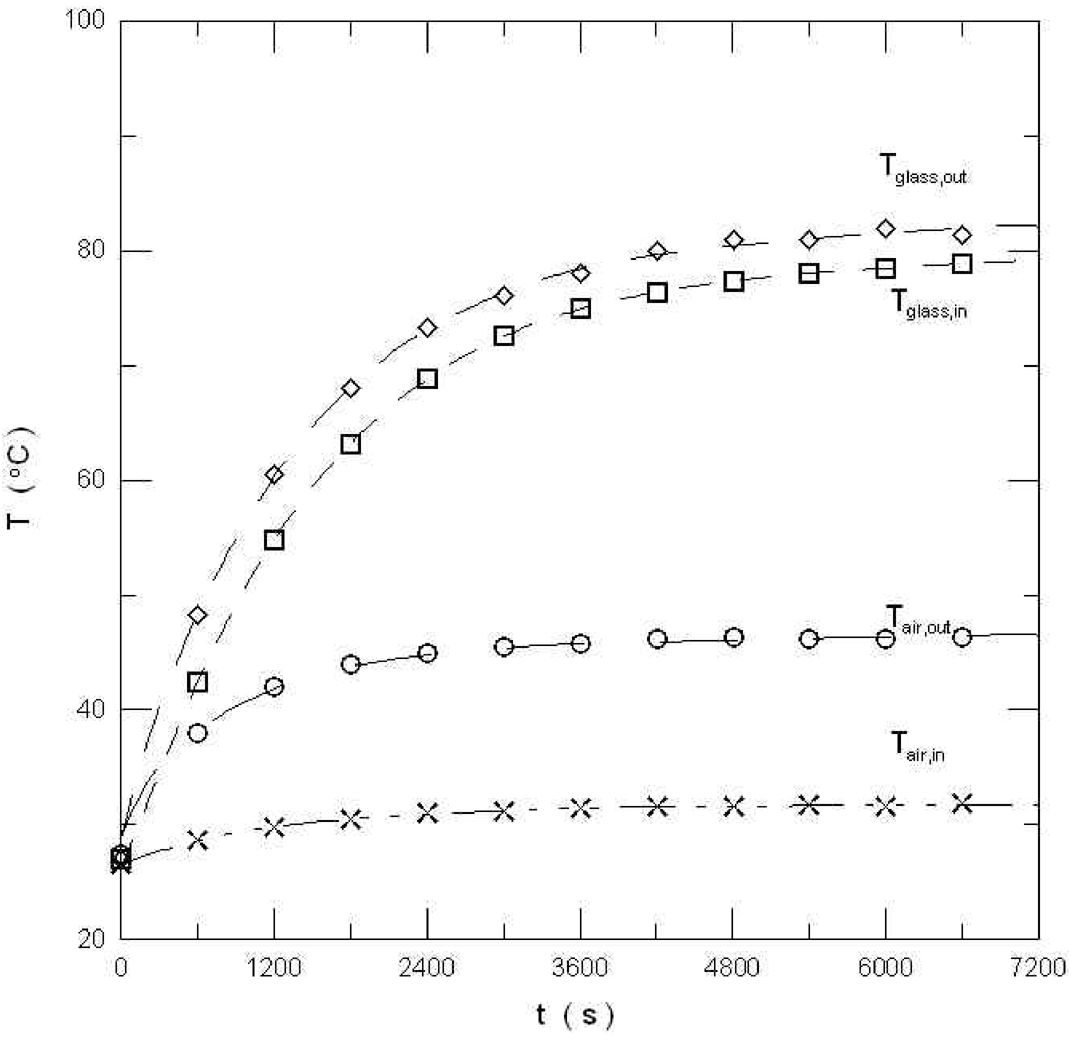


圖 3-11 6mm Low-E＋6mm 光膠合玻璃之溫度量測

(資料來源： 本研究整理)

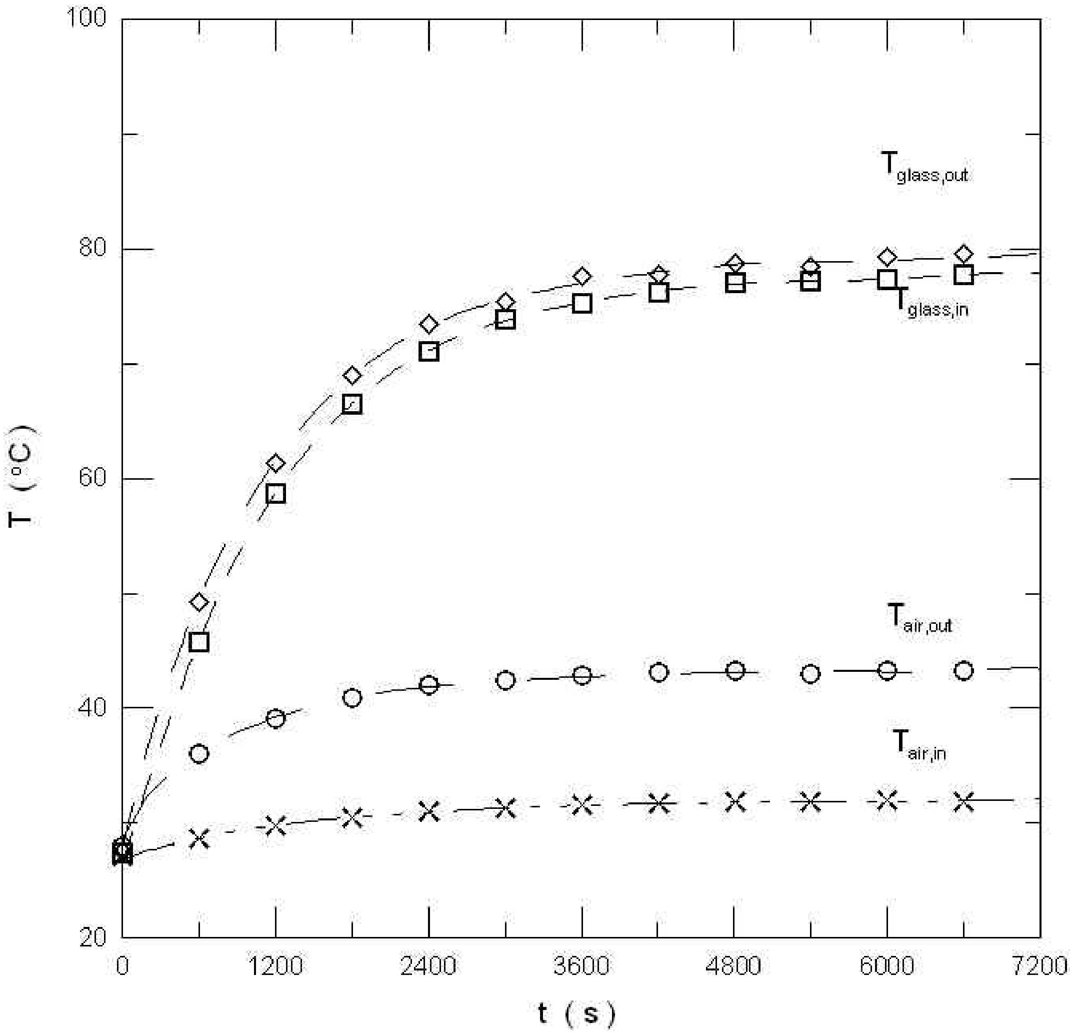


圖 3-12 光觸媒 6mm 綠＋6mm 光膠合玻璃之溫度量測

(資料來源： 本研究整理)

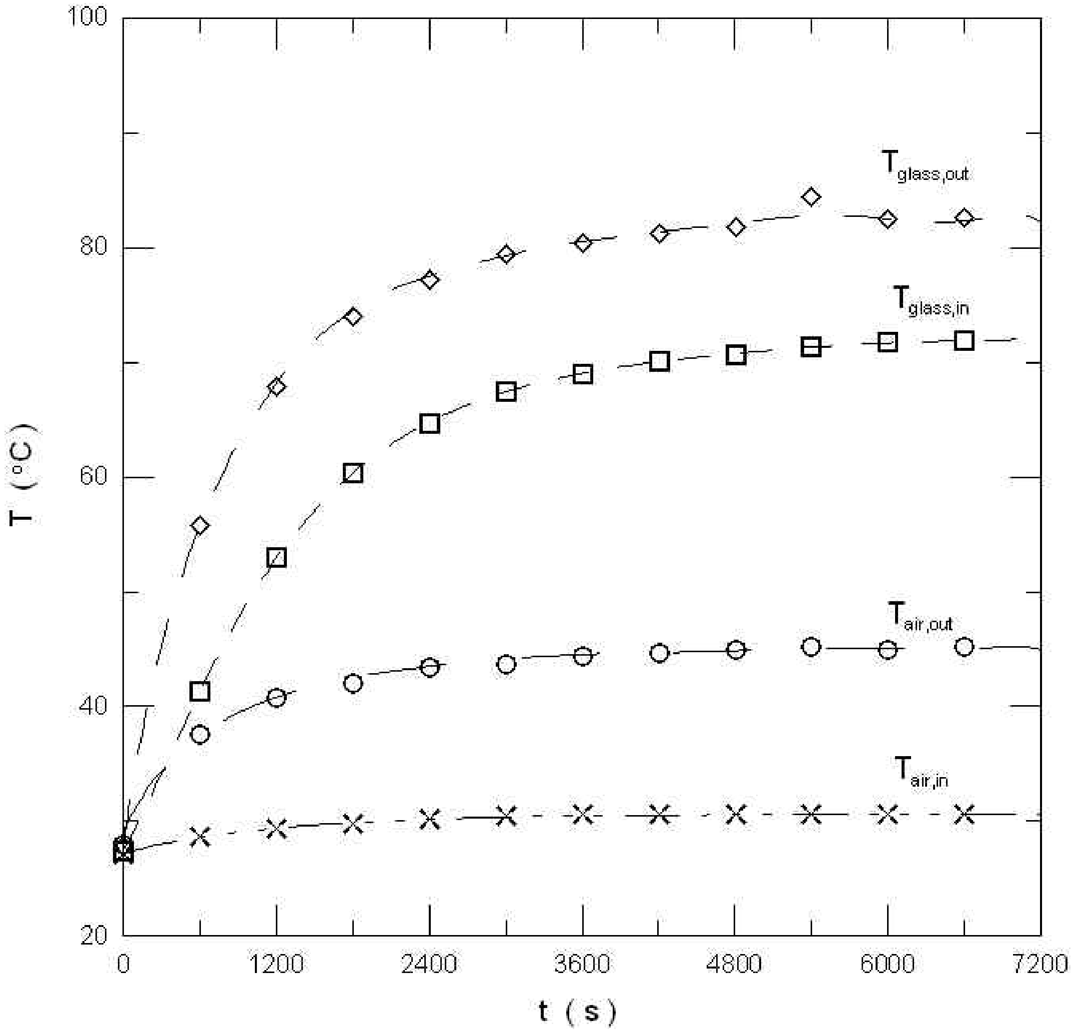


圖 3-13 6mm 綠＋12mm 空氣層＋6mm 光複層玻璃之溫度量測

(資料來源： 本研究整理)

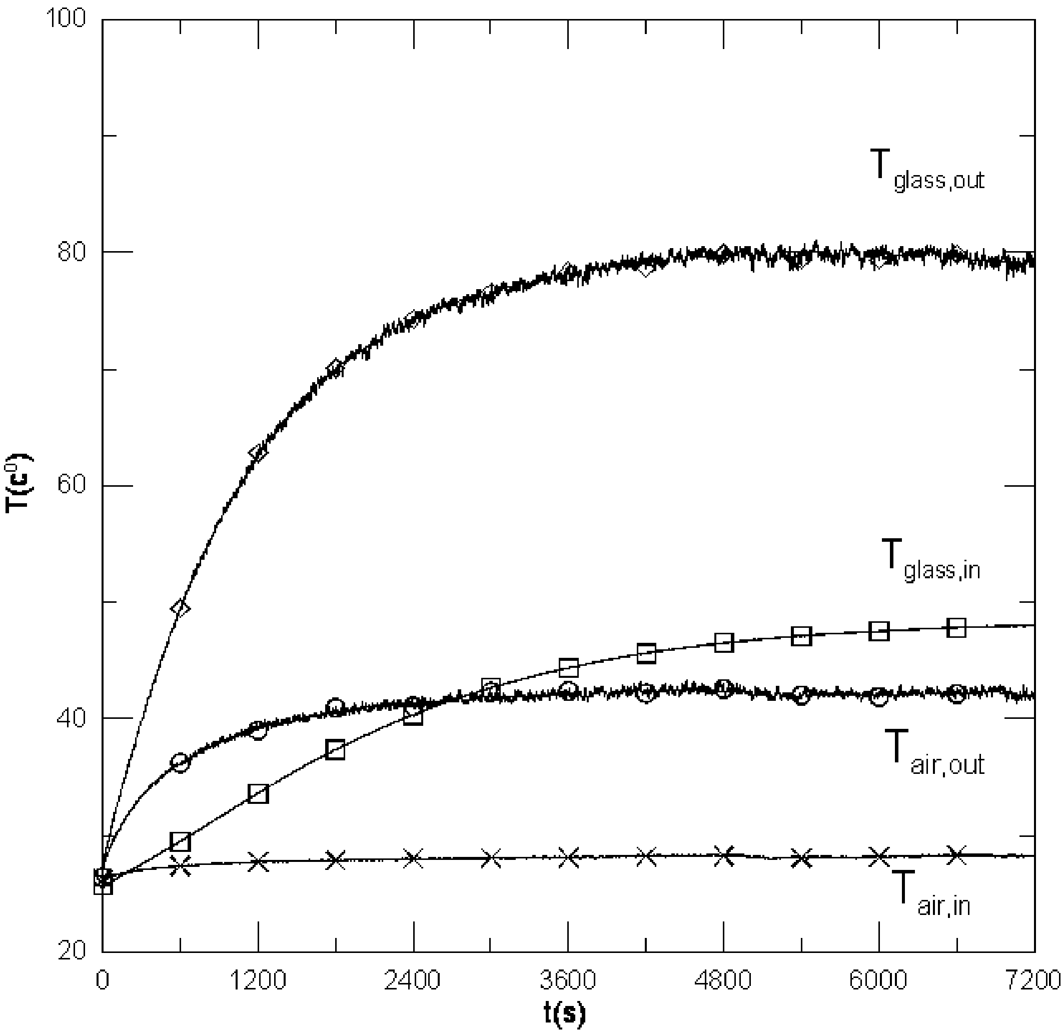


圖 3-14 6mm 綠＋12mm 空氣層＋隔熱膜＋12mm 空氣層＋6mm 光複層玻璃之溫度量測

(資料來源： 本研究整理)

第四節 小結

在進行完全尺度戶外曝曬實驗、鉛筆硬度實驗、耐磨耗實驗、耐酸鹼性實驗以及光照實驗後，研究結果顯示直接在玻璃上直接貼附隔熱膜是無法承受耐磨耗以及鉛筆硬度之測試，而且亦受高溫之影響而有氣泡產生，是所有試驗玻璃種類中耐候性能最差的。

另一方面，在光照實驗中吾人發現Low-E膜或隔熱膜在室外側時的玻璃室內側溫度會比Low-E膜或隔熱膜在室內側時的玻璃溫度還低。此玻璃表面溫度的差異，雖然影響直射進入玻璃的太陽輻射強度太多，但卻會影響藉由熱傳導形式進入室內的熱量，以及靠近玻璃附近人員之舒適性。本研究計畫獲得與現行Low-E膜或隔熱膜均在室內側的觀念相反之結果。然而，其原因在於隔熱膜貼附在玻璃室外側上，將無法承受外界環境而使得破壞原有之功用。而對於Low-E玻璃而言，當Low-E塗覆面置於室外側雖然能通過本研究之鉛筆硬度、耐酸鹼性、耐候測試，但是因為考量目前清潔玻璃帷幕外牆會使用含氫氟酸之鐵鏽清潔劑，以及常以刮刀去除沾黏在玻璃表面之油墨斑點，造成Low-E膜被損毀之可能性，故目前Low-E膜與隔熱膜均仍被裝置在室內側。因此，為了能提升此類節能玻璃之節能效果與室內熱舒適環境，並且防止上述破壞節能玻璃性能之可能性發生，若要將Low-E膜裝置在室外側，必須在Low-E膜外進行保護措施。

第四章 玻璃耐候試驗

根據上述有關玻璃使用材料之分析可知，使用在玻璃建材上的塑料、塗料或膠膜暴露在自然氣候條件和光照輻射下經一段時間後，可能會出現褪色、泛黃、剝落、裂開、喪失拉伸強度或整層脫落，甚至進而影響玻璃原有的光學性質等現象。因而，對於玻璃建材的耐候性和耐光性的性能測試就顯得十分重要。在第三章中，研究團隊已經針對玻璃建材的耐候特性，諸如硬度試驗、耐酸性、耐鹼性等進行量測與探討。但是對於玻璃建材在實際氣候下的劣化性能卻非第三章中的耐候特性量測就可以掌握。因此，本研究計畫在玻璃建材耐候性能測試之後，進行玻璃建材之耐候性測試。

根據研究團隊對於相關耐候性測試的標準方法收集與分析，目前普遍採用的耐候性測試有自然氣候老化試驗、氙弧燈（或碳弧燈）曝曬加速老化實驗與紫外線曝曬加速老化實驗等三種。以下為此三種耐候性測試方法之簡介：

(1) 自然氣候老化實驗

自然氣候老化實驗是國內外廣泛採用的方法。其主要優點是自然氣候老化實驗是最符合實際測試氣候條件的，所需要的實驗費用較少而且操作簡單方便。目前國際上較被認可的試驗場所為美國佛羅里達。而自然氣候老化實驗的缺點是試驗時間過長，再者戶外試驗氣候條件不可能年復一年完全相同，故試驗的再現性不佳。

(2) 氙弧燈（或碳弧燈）曝曬加速老化實驗

氙弧燈（或碳弧燈）曝曬加速老化實驗是目前國際上公認最能模擬全太陽光譜的耐候性試驗。氙弧燈（或碳弧燈）曝曬加速老化實驗方法是以氙弧燈（或碳弧燈）直接照射在玻璃試件上，在模擬潤濕條件時採用水噴淋或是溫度自動控制系統，來探討玻璃試件在曝曬於模擬太陽輻射與氣候條件下的耐候性。此方法所使用的光源可區分為氙弧燈與碳弧燈兩種，其測試的方法分別在 ASTM G155-05a: Standard Practice for Operating Xenon Arc Light Apparatus for Exposure of Non-Metallic Materials. 以及 ASTM G 152-06: Standard Practice for Operating Open Flame CarbonArc Light Apparatus for

Exposure of Non-Metallic Materials. 中有相關標準規範。氙燈的紫外光譜和可見光譜與太陽光譜非常接近，紅外線(800nm-1000nm)較強，發熱高。但從總光譜而言，氙弧燈的光譜是現有人工光源中最接近太陽光譜的，其模擬性比較好。

氙弧燈（或碳弧燈）曝曬加速老化實驗的限制在於氙弧燈（或碳弧燈）燈源的穩定性及試驗的複雜度。在氙弧燈（或碳弧燈）燈源的穩定性部分，由於氙弧燈（或碳弧燈）光源的光譜穩定性一般比螢光紫外線燈光源的光譜穩定性差，因此必須在氙弧燈（或碳弧燈）外配備輻射照度控制系統。根據相關文獻顯示一盞新的氙弧燈（或碳弧燈）與一盞使用過 1000 小時的氙弧燈（或碳弧燈）在短玻璃的光譜範圍內有顯著的變化。故為克服此試驗自身內在的限制，提高更換燈管的頻率或採用高精密的輻射照度控制系統等方法卻增加了此種試驗的複雜性。雖然氙弧燈（或碳弧燈）曝曬加速老化實驗有上述之缺點，但是在目前的試驗方法中氙弧燈（或碳弧燈）曝曬加速老化實驗仍是耐候性與耐日光照射試驗中最可靠和反應實際的方法。最近國際工業纖維協會 IFAI 强调氙弧燈曝曬加速老化實驗方法已發展作為汽車內部裝備，裝飾產品的老化試驗方法。事實上，許多試驗報告已證明產品利用氙弧燈曝曬加速老化實驗的結果與暴露在 Florida 試驗基地的自然老化试验结果相關性高達 98%。

表4-1 氙弧燈試驗方法標準主要條件比較

項 目		ISO4892.2-1994 塑料實驗室光源暴露試驗方法第2部分氙弧燈	GB9344-88 塑料氙燈光源暴露試驗方法	相應的國家標準
設備	光源光譜分佈	列出兩種試驗方法(A、B)紫外線輻射分佈和允差範圍	無	ASTM G155:2005 JIS K7350-4:1996 ISO 4892-2:1999
	輻照度	290nm-800nm 波長之間的通帶,選擇550w/㎡作為參考,或協商	300nm-890nm 波長時，選擇為1000±200w/㎡作為參考,或協商	
	噴淋水	蒸餾水或軟化水,固體物含量<1mg/L,水電導率<5μs/cm	自來水PH=6-8,必要時用蒸餾水或去離子	
測試條件	溫度	黑標準溫度(65±3)℃ 或(100±3)℃,可協商	黑板溫度(63±3)℃	
	相對濕度	(50±5)%或(65±5)%或協商	(65±5)%或其他	
	噴水週期	(18±0.5)min/(102±0.5)min	18min/102min或12min/48min或其他	
	黑暗週期循環	可設定	無	
	附錄	介紹空氣冷卻和水冷卻氙弧燈裝置	無	

(資料來源： 本研究整理)

(3) 紫外線曝曬加速老化實驗

紫外線曝曬加速老化實驗是利用螢光紫外線燈源模擬太陽光對耐久性材料的破壞性作用。紫外線曝曬加速老化實驗與上述氙弧燈（或碳弧燈）曝曬加速老化實驗不同之處在於螢光紫外線燈源在電學原理上與普通的照明日光燈相似，但能生成更多的紫外光而非可見光或紅外線。紫外線曝曬加速老化實驗並不是要模擬太陽光的照射,而是要模擬出太陽光對試件的破壞效果。

對於不同的試件，紫外線曝曬加速老化實驗中有不同的曝曬條件設定；因而有不同光譜的燈源可供選擇。目前以 UVA-340 與 UV-B 兩種燈源最常被使用。UVA-340 燈源在短波長紫外線光譜範圍與太陽光光譜相近，特別是在波長 360nm 處。而 UV-B 燈源則是被常用在曝曬加速老化實驗中。因 UV-B 燈源比 UVA-340 燈源對材料的破壞速度更快，但 UV-B 在波長小於 360nm 的能量輸出會對許多材料造成偏離實際的試驗結果。

目前所有的燈源均會隨時間老化而變弱。但是螢光紫外線燈與其他類型（如氙弧燈或碳弧燈）不同之處在於螢光紫外線燈的光譜穩定性高，其光譜能量分佈隨時間不會產生太大的變化。根據文獻顯示一盞使用 2 小時的螢光紫外線燈和使用 5600 小時螢光紫外線燈的光譜能量分佈並無變化。此特點也是紫外線曝曬加速老化實驗的實驗再現性高的原因。

本研究團隊根據上述三種常用耐候性試驗方法與標準分析比對後，認為適用紫外線曝曬加速老化實驗以及氙弧燈（或碳弧燈）曝曬加速老化實驗兩種試驗方法來探討玻璃建材耐候性。

第一節 紫外線曝曬加速老化實驗

根據 C.Decker (2004)等研究發現太陽中紫外線會讓塗覆在玻璃物質或膠膜吸收值發生變化，進而影響節能玻璃採光品質，如圖 4-1 所示。因此本研究擬採用 QUV 耐候試驗機模擬陽光照射，預計進行市售 8 種節能玻璃之紫外線曝曬加速老化實驗實驗。

一、儀器規格說明：

1. 本研究使用之 QUV 耐候試驗機為一模擬室外氣候條件造成物件損壞程度之實驗設備，以 UV 光模擬太陽光對物體之破壞，以冷凝或噴水系統模擬雨水或濕氣影響，只需要幾天或幾周的時間，就可以再現戶外需要數月或數年所產生的破壞。其表面損壞現象包括開裂、脆化、光澤變化或氧化等。

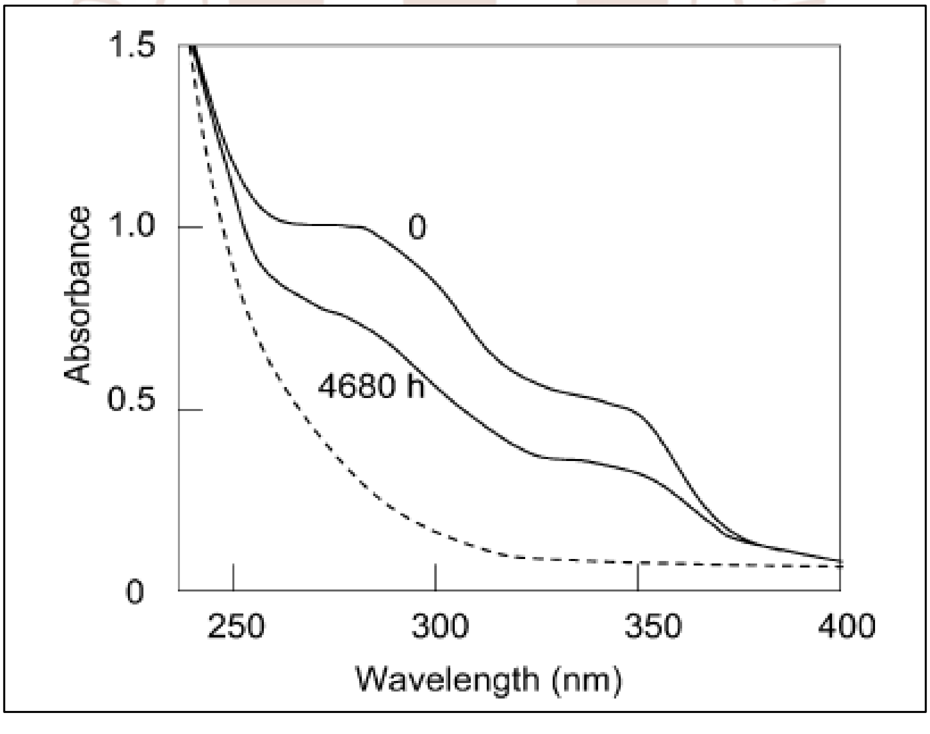


圖 4-1 玻璃曝曬後之吸收值（透光率）變化

(資料來源： 本研究整理)

(資料來源： 本研究整理)

圖 4-2 QUV 耐候試驗機

(資料來源： 本研究整理)

圖 4-3 紫外線燈管與試件配置

2.實驗步驟：

2.1 裁切實驗試件與實驗前準備

2.2 將試驗試件於儀器試件架

2.3 進行第一循環實驗量測

2.4 更換試件位置，重複步驟3繼續進行實驗。

2.5 重複步驟3~4，直到設定量測時間。

3.注意事項：

3.1 QUV燈管會導致對眼睛傷害，若沒有UV護目鏡，請勿直視。

3.2 打開儀器移動樣品前，應關閉UV燈管。

3.3 勿使用一般燈管裝至QUV上。

第二節 紫外線曝曬加速老化實驗結果

本研究擬採用QUV耐候試驗機模擬陽光照射，並進行市售8種節能玻璃實驗。探討參數包括：

(1) 可見光穿透率

(2) 日光入射之演色性Ra、色溫、色度

表4-2與4-3為進行紫外線曝曬加速老化實驗照射前與1000小時照射後之實驗結果。由實驗的數據可知，八種玻璃建材的可見光穿透率在照射紫外線1000小時後並無顯著的差異。而在演色性與色溫上，玻璃建材的演色性與色溫受紫外線的影響亦是無法在1000小時的曝曬顯現出來。

表4-2 QUV曝曬加速老化照射前實驗結果

試驗試件	可見光穿透率	演色性 Ra	色溫	色度
1.三層玻璃: 6mm 綠色玻璃（外） +6AS+Low-E 隔熱膜 +6AS+6mm 清玻璃(室內)	52.23%	89.34%	7105 K	(0.2994，0.3404)
2.複層玻璃 6mm 綠色玻璃(室外) + Low-E Coating+12AS+6mm 清玻璃（室內）	52.21%	89.29%	6753 K	(0.3050，0.3464)
3.單層玻璃 6mm 清玻璃+O 隔熱紙	34.97%	96.92%	7177 K	(0.3017，0.3243)
4.單層玻璃 6mm 清玻璃+P 隔熱紙	66.50%	97.23%	6720 K	(0.3081，0.3321)
5.單層玻璃 6mm 清玻璃+ATO 鍍膜	60.67%	96.16%	7067 K	(0.3027，0.3281)
6.膠合玻璃 6mm 綠玻璃 +0.76mmPVB 膠合膜 +6mm 玻璃	71.34%	90.24%	7169 K	(0.2988，0.3382)
7.半反射玻璃	31.40%	98.22%	4369 K	(0.3671，0.3746)
8.單層玻璃 6mm 清玻璃+Q 隔熱紙	59.31%	87.12%	6205 K	(0.3154，0.3571)

(資料來源： 本研究整理)

表4-3 QUV曝曬加速老化實驗結果（照射1000小時）

試驗試件	可見光 穿透率	演色性 Ra	色溫 K	色度
1.三層玻璃: 6mm 綠色玻璃（外） +6AS+Low-E 隔熱膜 +6AS+6mm 清玻璃（內）	52.15%	89.33%	7111 K	(0.2993，0.3404)
2.複層玻璃 6mm 綠色玻璃（外） +Low-co ating+12AS+6mm 清玻璃（內）	52.18%	89.25%	6762K	(0.3049，0.3464)
3.單層玻璃 6mm 清玻璃+O 隔熱紙	35.04%	96.94%	7162 K	(0.3020，0.3244)
4.單層玻璃 6mm 清玻璃+P 隔熱紙	66.48%	97.15%	6706 K	(0.3083，0.3325)
5.單層玻璃 6mm 清玻璃+ATO 鍍膜	61.23%	95.93%	7047 K	(0.3029，0.3289)
6.膠合玻璃 6mm 綠玻璃+0.76mmPVB 膠合膜+6mm 玻璃	71.17%	90.23%	7180 K	(0.2986，0.3381)
7.半反射玻璃	31.40%	98.23%	4375 K	(0.3669，0.3745)
8.單層玻璃 6mm 清玻璃+Q 隔熱紙	59.51%	87.30%	6204 K	(0.3155，0.3568)

(資料來源： 本研究整理)

第二節 氙弧燈（或碳弧燈）曝曬加速老化實驗

本研究團隊接著以碳弧燈模擬實際太陽光曝曬，進行曝曬加速老化試驗。本研究團隊因考量測試時間，決定以在紫外線光譜能量較高的碳弧燈取代氙弧燈進行玻璃建材耐候性試驗。

本研究共試驗 10 種玻璃建材。此 10 種玻璃建材的選用考量係依據第二章之耐候性能測試結果，分別針對隔熱膜、Low-E 玻璃、光觸媒塗覆以及密封塑膠材等因子進行選取。惟因試驗時間與測試設備空間之故，僅能選取 10 種代表性的玻璃建材進行測試，對於普遍認同不會受氣候影響之玻璃建材，本研究並未納入。此 10 種玻璃建材分別為(1) 6mm 綠玻璃、(2) 6mm 半反射玻璃、(3) 6mm Low-E 玻璃、(4) 6mm 光觸媒玻璃、(5) 6mm 貼附隔熱膜玻璃、(6) 6mm 清＋6mm 綠膠合玻璃、(7) 6mmLow-E＋6mm 綠膠合玻璃、(8) 12mm 膠合＋6mm 綠光觸媒雙層玻璃、(9) 6mm 清＋6mm 清雙層玻璃（結構膠密封）、(10) 6mm 清＋6mm 清雙層玻璃（熱溶膠密封）。

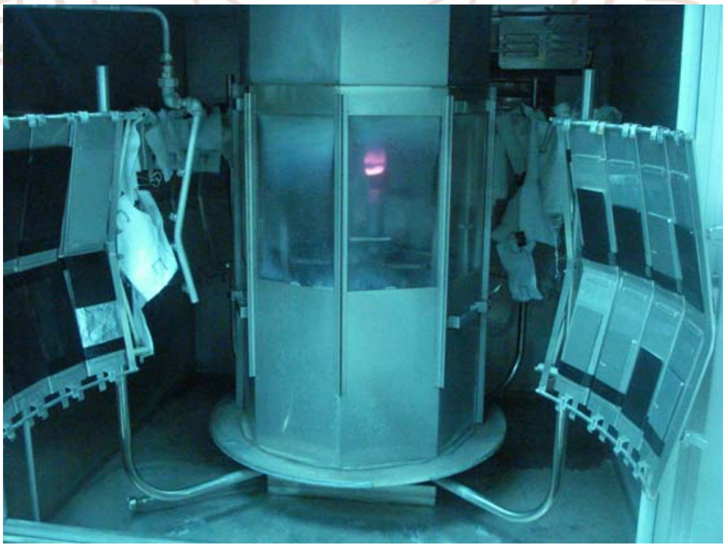
本研究計畫依據 G152-06 之測試標準，採用日本 SUGA WS type 生產之碳弧燈耐候試驗機進行玻璃試件之耐候性測試。圖 4-4 為碳弧燈耐候試驗機之外觀，圖 4-5 碳弧燈耐候試驗機燈源與試件配置圖。本研究之實驗操作程序亦是依據 G152-06 之標準，其實驗流程敘述如下：

- 裁切實驗試件以符合安裝尺寸與實驗前準備。
- 將試驗試件於儀器試件架。
- 設定模擬氣候條件。
- 進行第一循環實驗量測。
- 更換試件位置，重複上述步驟繼續進行實驗。
- 重複步驟 3~4，直到設定量測時間。

■ 量測相關耐候性能。

(資料來源： 本研究整理)

圖 4-4 碳弧燈耐候試驗機



(資料來源： 本研究整理)

圖 4-5 碳弧燈管與試件配置圖

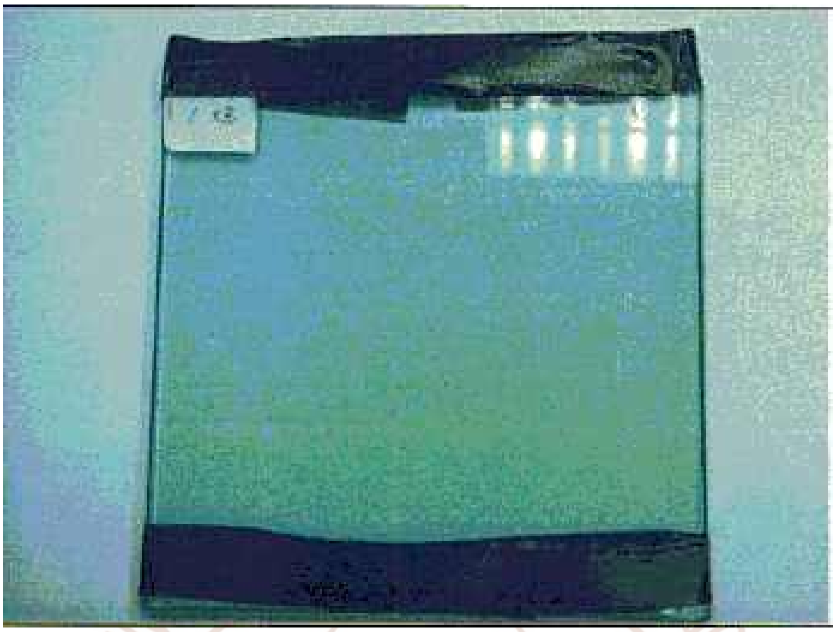
在模擬氣候條件條件之設定方面，在 G152- 06 中規定各種模擬條件之設定值，如表 4-4 所示。其中 cycle 1 為最常被使用的氣候條件，cycle 2 通常被用在室外裝修材料的測試，cycle 3~5 通常被用在室外塗料或染料之試驗上。在本研究計畫中，則是採用 cycle 1 的模擬氣候條件。先進行 102min 在黑板溫度 63（±3）℃下照光試驗，接著進行 18min 未控制溫度下照光與噴淋水試驗。總試驗時間為 1000 小時。俟試驗時間結束後再進行表面外觀檢查以及可見光穿透率測試，確認玻璃試件在碳弧燈曝曬加速老化試驗後之耐候性。

圖 4-6～4-16 為 10 種玻璃試件經過 1000 小時碳弧燈曝曬加速老化試驗後之玻璃外觀圖。從圖 4-6～4-10 可知，對於單層玻璃而言，無論是半反射玻璃、Low-E 玻璃或是光觸媒玻璃經過碳弧燈曝曬後的玻璃外觀以及可見光穿透率並未有老化或衰減的現象產生。但在圖 4-10 的 6mm 貼附隔熱膜玻璃在曝曬試驗後，整個玻璃表面在貼附隔熱膜處完全變為霧化，可見光穿透率大為降低。因此由試驗結果可推論，單層玻璃的耐候性與受日光照射面是否有進行硬化處理有關。對於清玻璃、半反射玻璃、Low-E 玻璃或是光觸媒玻璃只要在塗覆表面有硬化處理過，則無論是硬度試驗、耐酸鹼試驗或是曝曬試驗均顯示其光學性能不會受氣候之影響而劣化。而對於膠合玻璃而言，研究團隊欲探討 PVB 膜的耐候性。根據圖 4-11～4-12 的試驗後結果顯示，無論是兩片清玻璃組成的膠合玻璃或是由 Low-E 玻璃與清玻璃所組成的膠合玻璃並不會受曝曬條件影響而有致使玻璃光學性能的劣化。因此，膠合玻璃的 PVB 膜在 1000 小時的碳弧燈曝曬加速老化試驗後並不會影響玻璃建材的耐候性。圖 4-14～4-16 為複層玻璃以矽利康與熱熔膠為密封材質的試驗結果。從圖 4-14 與 4-15 的結果可知，雙層玻璃的光學性質並未有所不同。但是由圖 4-16 可知，熱熔膠在經過 1000 小時的曝曬之後，會出現軟化以及拉伸能力不夠的現象，而導致熱熔膠無法完全如試驗前包覆複層玻璃。

表 4-3 ASTM G152-06 之模擬設定氣候條件

cycle	Filter	Exposure Cycle
1	Daylight	102min 在黑板溫度 63（±3）℃下照光，18min 未控制溫度下照光與噴淋水
1a	Extended UV	102min 在黑板溫度 63（±3）℃下照光，18min 未控制溫度下照光與噴淋水
2	Daylight	90min 在黑板溫度 77（±3）℃、相對濕度 70（±5）%下照光，30min 未控制溫度下照光與噴淋水
3	Daylight	102min 在黑板溫度 63（±3）℃下照光，18min 未控制溫度下照光與噴淋水。反覆 9 次直到試驗時間為 18 小時。接著在在黑板溫度 24（±2.5）℃、相對濕度 95（±4.0）%下未照光 6 小時。
3a	Extended UV	102min 在黑板溫度 63（±3）℃下照光，18min 未控制溫度下照光與噴淋水。反覆 9 次直到試驗時間為 18 小時。接著在在黑板溫度 24（±2.5）℃、相對濕度 95（±4.0）%下未照光 6 小時。
4	Daylight	4 小時在黑板溫度 63（±3）℃下照光，4 小時未控制溫度下照光與噴淋水
5	Daylight	12 小時在黑板溫度 63（±3）℃下照光，12 小時未控制溫度下照光與噴淋水
6	Window Glass	100%全部在黑板溫度 63（±3）℃下照光

(資料來源： 本研究整理)

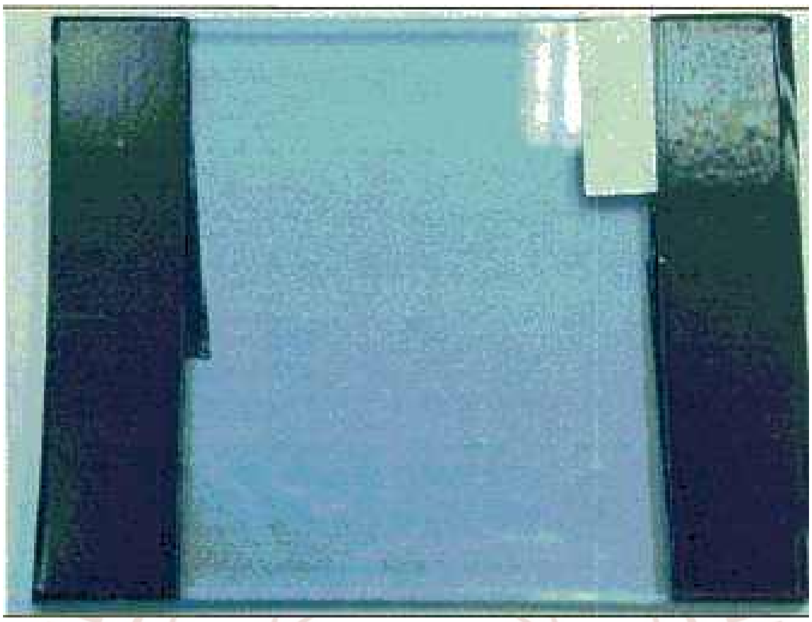


(資料來源： 本研究整理)

圖 4-6 6mm 綠玻璃

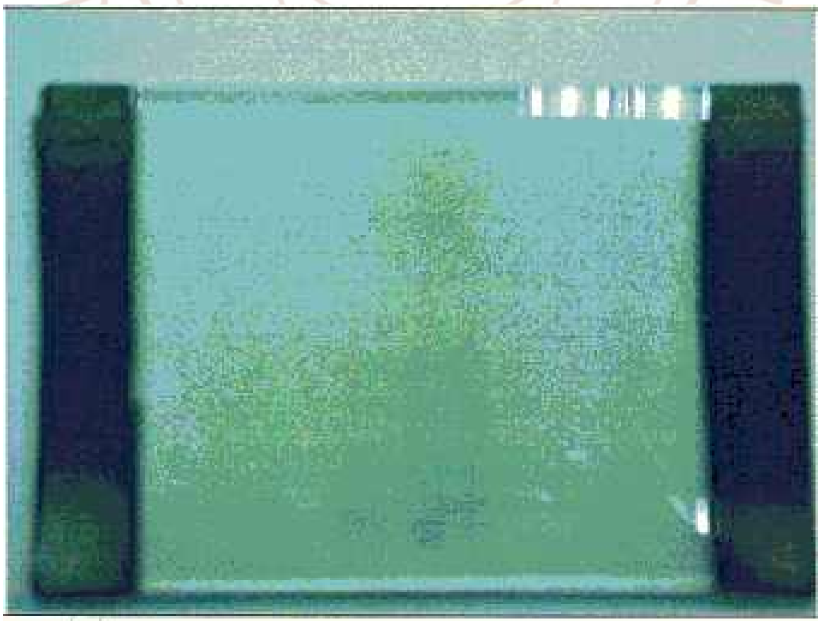
(資料來源： 本研究整理)

圖 4-7 6mm 半反射玻璃



(資料來源： 本研究整理)

圖 4-8 6mm Low-E 玻璃

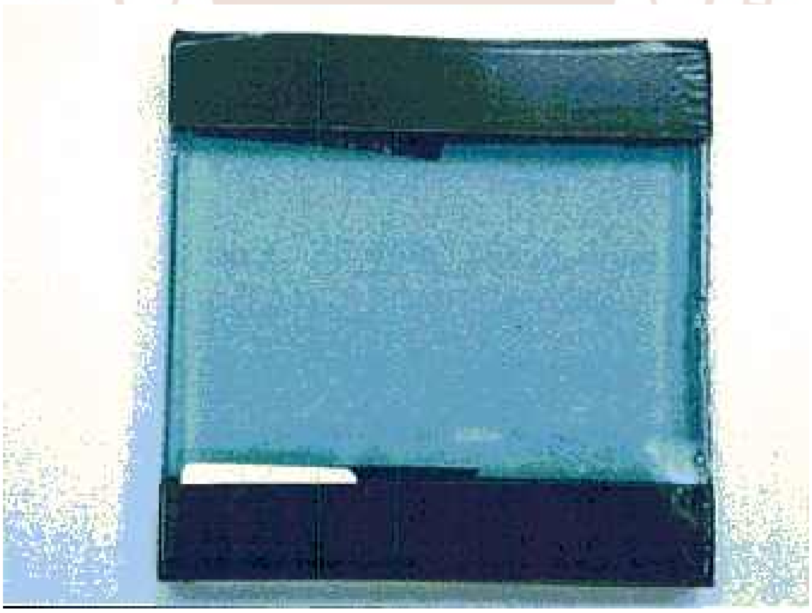


(資料來源： 本研究整理)

圖 4-9 6mm 光觸媒玻璃

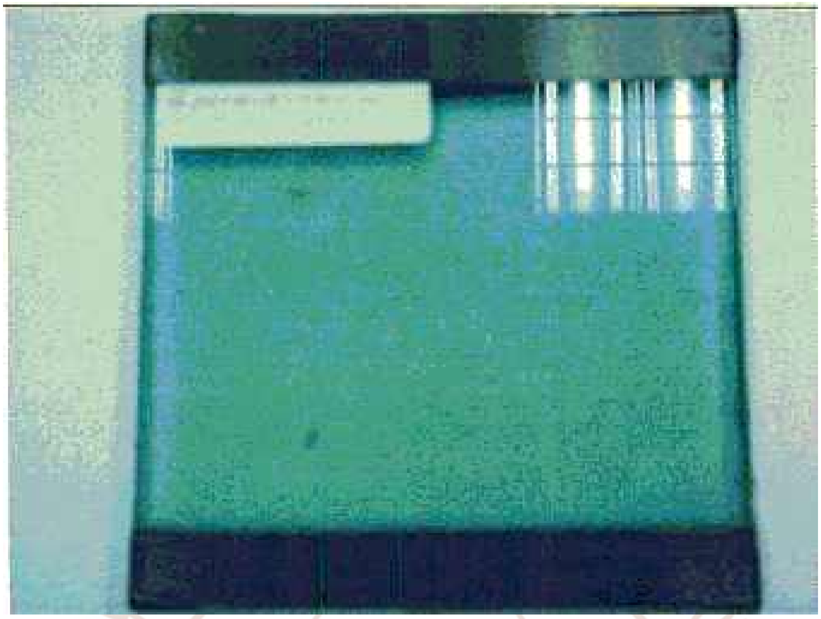
(資料來源： 本研究整理)

圖 4-10 6mm 貼附隔熱膜玻璃



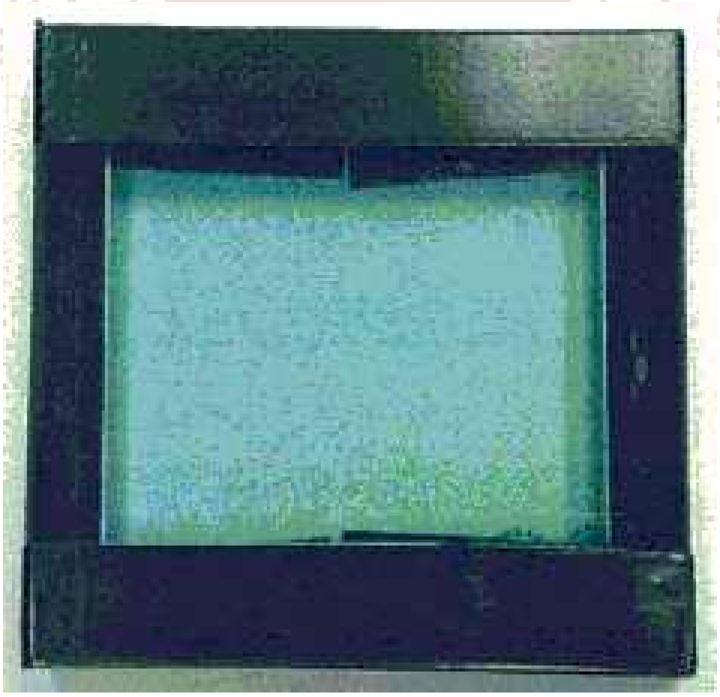
(資料來源： 本研究整理)

圖 4-11 6mm 清＋6mm 綠膠合玻璃



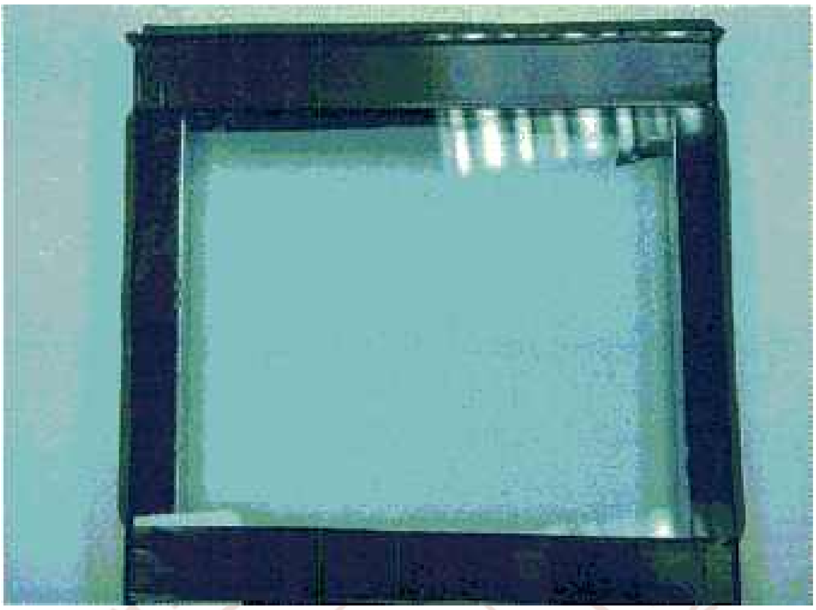
(資料來源： 本研究整理)

圖 4-12 6mmLow-E＋6mm 綠膠合玻璃



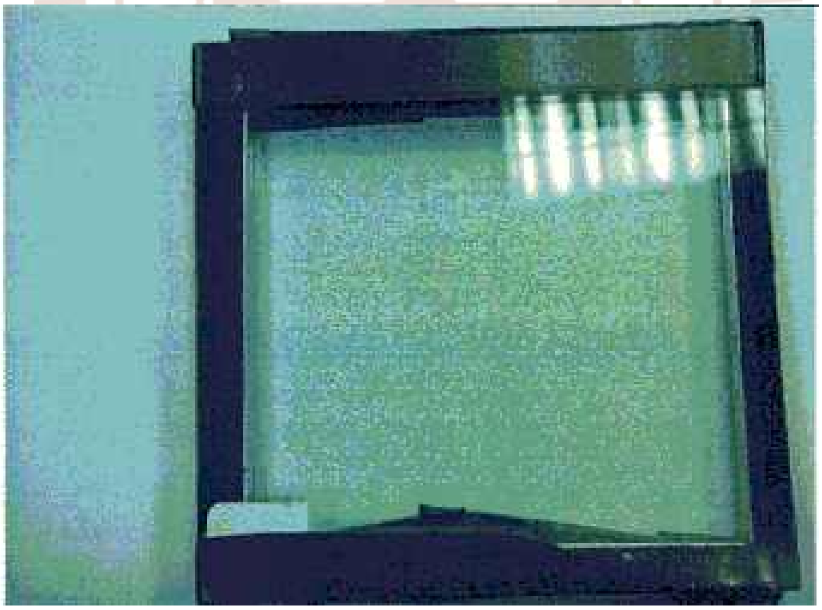
(資料來源： 本研究整理)

圖 4-13 12mm 膠合＋6mm 綠光觸媒雙層玻璃



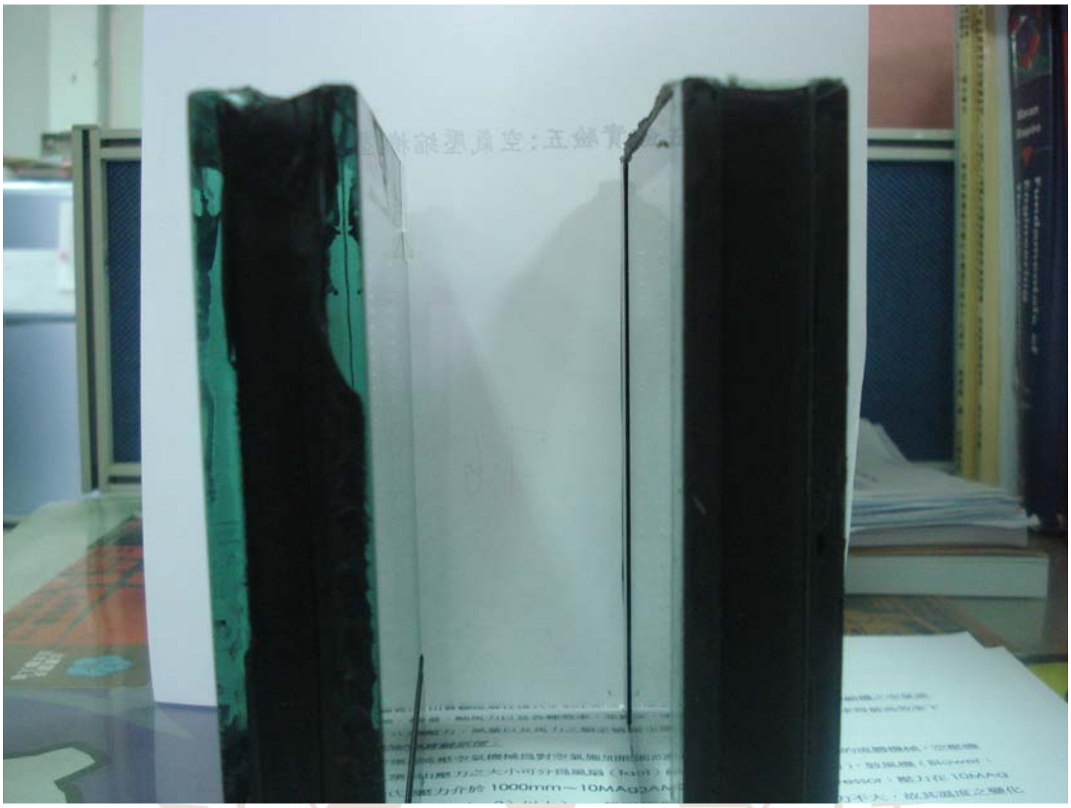
(資料來源： 本研究整理)

圖 4-14　6mm 清＋6mm 清雙層玻璃（結構膠密封）



(資料來源： 本研究整理)

圖 4-15　6mm 清＋6mm 清雙層玻璃（熱溶膠密封）



(資料來源： 本研究整理)

圖 4-16 結構膠密封與熱溶膠密封之試驗結果

第五章 結論與建議事項

本研究計畫於執行期間，首先透過相關CNS玻璃建材之定義與檢測方法，探討各種玻璃建材中會影響其耐候特性之因素，了解目前影響玻璃耐候特性的因子計有(1) 雙層玻璃之密封膠、(2) Hard Low-E 鍍膜、(3) 隔熱貼膜以及(4) 光觸媒塗膜。因而，本研究計畫依據玻璃耐候性能檢測法訂定與本年度研究主題相符之檢測項目。共有(1) 全尺度室外曝曬實驗、(2) 鉛筆硬度試驗、(3) 耐候性試驗、(4) 耐磨耗性試驗、(5) 耐酸性試驗、(6) 耐鹼性試驗、(7) 玻璃光照試驗等七項試驗項目。針對玻璃建材之耐候性獲得豐碩的實驗結果。研究結果顯示隔熱膜的貼附會在日照下有氣泡而影響其耐候性，再者，隔熱膜的硬度以及耐酸鹼等耐候特性亦不符合CNS的要求。而且由碳弧燈曝曬加速老化實驗中，吾人更發現隔熱膜貼附在玻璃上因為未有任何表面硬化處理，而致使隔熱膜產生劣化而使可見光穿透率大大降低。而對於雙層玻璃之密封膠對於玻璃耐候性部分，在雙層玻璃分別以矽利康以及熱熔膠密封受到碳弧燈曝曬加速老化實驗後之結果發現，熱熔膠並不能承受曝曬實驗的模擬氣候條件，而有軟化以及拉伸強度不足等現象產生。

本研究除了獲得影響玻璃建材耐候性能之因子外，在研究計畫中的光照實驗結果上，研究團隊發現Low-E膜在室外側時的玻璃室內側溫度會比Low-E膜在室內側時的玻璃溫度還低。此玻璃表面溫度的差異，雖然不會影響直設進入玻璃的太陽輻射強度，但卻會影響藉由熱傳導形式進入室內的熱量，以及靠近玻璃附近人員之舒適性。本研究計畫獲得與現行Low-E膜均在室內側的觀念相反之結果。

目前本研究計畫業已完成對於本研究計畫之研究結果詳列如下：

(1) 完成玻璃建材耐候特性之CNS標準試驗方法收集與分析。

(2) 建立全尺度室外曝曬實驗。

(3) 完成三種玻璃之鉛筆硬度試驗。

(4) 完成三種玻璃耐磨耗性試驗。

(5) 完成三種玻璃耐酸性試驗。

(6) 完成三種玻璃耐鹼性試驗。

(7) 完成六種玻璃之玻璃光照試驗。

(8) 完成紫外線曝曬加速老化實驗。

(9) 完成碳弧燈曝曬加速老化實驗。

後續研究建議

本研究計畫除完成上述研究成果外，於計畫執行過程中對於節能玻璃建材的耐候性能之影響因子有系統性的研究，故針對與本研究計畫相關之未來研究方向提供下列建議事項：

1. 由本研究計畫之成果可知，玻璃建材的耐候性能上之最重要影響因素為隔熱膜的耐候性，故對於玻璃建材或隔熱膜的耐候性量測實屬必要。因此建議性能實驗中心可建立氙弧燈曝曬加速老化試驗，藉由此標準量測程序之建立，使得性能實驗中心具有玻璃建材、隔熱膜或相關塗料之耐候性測試技術。

2. Low-E玻璃或隔熱膜雖具有吸收太陽輻射能量之優點，然而此類玻璃吸收的熱量造成玻璃表面溫度上升，在實際影響室內人員熱舒適性上，卻是必須加以考量。因此對於在台灣氣候條件下，節能玻璃對室內人員熱舒適性之影響值得進一步探討。特別針對在屋頂天窗以及建築物外牆部分，節能玻璃建材光學和熱學性質與熱舒適性的關連性，亦需加以瞭解。

3. 在本研究計畫中對於光觸媒塗層玻璃之耐候性能試驗上仍屬缺乏，世界各國對於光觸媒玻璃之耐候性能並未有相對應的試驗方法與規範公布。雖然本研究計畫透過相關業者之協談與其他標準探討後，列出相關之規範，但是針對光觸媒玻璃之親水性與光觸媒塗層附著力試驗等方法仍須進一步之探討與建立，故此部分可列為後續之研究主題，期使光觸媒在節能玻璃之應用上能因試驗方法與規範之確立，而能被更廣泛應用在建築玻璃上。

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附　　錄

附錄 1

期中簡報審查會議記錄及處理情形

專家學者審查意見與建議		意見回覆及處理情形
台灣省建築材料商業同業公會聯合會（王總幹事榮吉）		
1.1	本研究案之玻璃建材應用之調查技術資料，均已大致完成預期之目的。	敬悉
1.2	建請未來能將 Low-E 玻璃室內、室外之光照實驗，就不同環境、情境、溫度、溼度等，作實測比對分析其變化情形。	本年度研究計畫並未針對 Low-E 玻璃進行全尺度實驗，然委員之意見將會列入未來之研究方向參考。
施副總經理人豪（張經理雅聰代表）		
2.1	第二章第三節低輻射 Low-E 玻璃，文中提及台灣玻璃公司生產為 Soft Low-E，但在第三章耐候試驗卻未包含此種玻璃。	對於 Soft Low-E 玻璃產品之耐候性能，本研究計畫主要是探討複層玻璃密封膠之耐候性，而非針對在複層玻璃空氣層內之 Soft Low-E 膜。相關說明請參考第三章第一節。
2.2	第三章第三節光照實驗選定 6 種玻璃，其中前 4 項皆使用進口品佔 2/3，國外產品比率偏高。	本研究計畫光照實驗之實驗設計參數，已補充說明於第三章第三節。

2.3	第三章第二節提及 CNS 13032 之鉛筆硬度要求值：≧8H，但實際並無此項要求。	已更改。
2.4	計畫為節能玻璃性能研究，光觸媒產品節能效果有限，且試驗僅取一種塗佈方式之單一產品及單一廠商，建議不應包含在此一計畫內。	有關光觸媒產品之測試主要是著重未來此產品之應用可能性，並且針對其耐候性能進行探討，而節能效果部分則是取決於玻璃種類。
2.5	既為建築物省能的參考依據，不應著重某些產品，有失客觀合理性及全面性。	遵照辦理。
陳教授寒濤		
3.1	P22.Fig.2-10：建議公司的名稱不要列在報告中。	遵照辦理。
3.2	P22 及 P27：建議全尺度的玻璃長與寬能標示清楚。	遵照辦理。
3.3	P24 及 P25：是否製作工法沒缺失，中間夾層的隔熱膜就不會有如圖 3-3 的氣泡發生。	以目前隔熱膜黏貼工法確實會出現氣泡。
蕭教授弘清		
4.1	本研究執行至期中階段進行許多性能量測深具學術分析研究價值，成果令人振奮而值得肯定。	敬悉。
4.2	建議本研究按既定進度繼續測試，及將成果推廣予業界參考，以開發實際成品並正確應用，對於節能推廣深具意義。	遵照辦理。

4.3	不論任何材料（包括光觸媒）之真正成效均宜廣泛納入測試。	遵照辦理。
本所陳組長瑞鈴		
5.1	Low-E塗膜放在內層或外層較有節能功效？請執行單位補充說明。	已於第三章第三節補充說明。

附件 2

期末簡報審查會議記錄及處理情形

專家學者審查意見與建議		意見回覆及處理情形
台灣省建築材料商業同業公會聯合會（王總幹事榮吉）		
1.1	建請本研究案未來能加入進口玻璃業及塗膜等相關業者之實驗數據，俾供實務運用，及增加未來預期成果。	敬悉
1.2	建請補充各國節能玻璃判定基準，俾供參考比較。	
台灣區照明燈具輸出業同業公會（宋專員福生）		
2.1	披覆有光觸媒的玻璃建材，其光觸媒可藉由濺鍍物理蒸鍍，或以擦塗、滾塗、浸塗、噴塗、刷塗等方式加到玻璃表面，並經高溫固化燒結，可與任何市面上加工的玻璃建材產品如強化玻璃、膠合玻璃、複層玻璃搭配應用。在光觸媒玻璃之耐候特性檢測部分，除了玻璃之耐候性、耐磨性以及耐酸鹼性試驗外，亦需針對親水性與光觸媒塗層附著力試驗等進行規範，希望列為後續研究之題材。	有關光觸媒玻璃之親水性與光觸媒塗層附著力試驗等規範已遵照委員意見辦理，列在第五章之後續研究建議第三點。
施副總經理人豪（張經理雅聰代表）		
3.1	節能玻璃仍未有定義，台灣現僅有貴所訂定之高性能節能玻璃綠建材評估基準，此研究案選定的各種樣品是否能符合評估基準遮蔽係數≦0.35、可見光反射率≦0.25，可見光穿透率≧0.5 的要求？	有關本研究計畫主題之節能玻璃定義已於第一章第三節補充說明。

3.2	此研究報告參考的 ASTM 標準皆是針對 NON-Metallic Material 之耐候試驗，換言之即是針對美國 Southwall 公司之專利產品 Heat Mirror 之 PET 膠片作耐候試驗，樣品內完全未包含世界主要玻璃廠商如 PPG、PILK、AFG、Saint-Gobain 等生產的 Soft-Low-E 產品。	對於 Soft Low-E 玻璃產品之耐候性能，本研究計畫主要是探討複層玻璃密封膠之耐候性，而非針對在複層玻璃空氣層內之 Soft Low-E 膜。相關說明請參考第三章第一節。
陳教授寒濤		
4.1	建議將節能玻璃定義清楚。	有關本研究計畫主題之節能玻璃定義已於第一章第三節補充說明。
張教授又升		
5.1	模擬光源實驗儀器在熱傳上似乎還有限制，會造成實驗數據說服力不足。	模擬光源實驗儀器雖與實際玻璃光照條件有所差異，然本研究計畫所量測之實驗數據業與國立成功大學機械系逆向熱傳實驗室之量測數據進行比對，以增加實驗數據之可信度。
5.2	本研究所用玻璃多非市面上常使用之大宗，應用成果恐受限。	本研究計畫所探討之節能玻璃範圍與限制已於第一章第三節補充說明。而對於本研究計畫所探討影響玻璃耐候性之因素，亦可適用在市售玻璃

		上。
5.3	本研究案建立玻璃建材耐候性能試驗標準，值得肯定，惟後續市售產品性能驗證仍宜由廠商自費送測。	敬悉
楊教授冠雄		
6.1	我國由於綠建築相關政策推展極為成功，因此對於節能玻璃之需求日益殷切。然而，節能玻璃之耐候性及實際之應用情況一直缺少系統化之研究分析，本案之完成，已對此方面做出具體貢獻。	敬悉
6.2	計畫已達成預期目標，成果良好。	敬悉
蕭教授弘清		
7.1	本期末報告中未見有關期中報告之建議事項的修正情況，但內容詳盡、並有具體的研究成果呈現，與預定之研究目標相符合，可以接受。	遵照辦理。
7.2	本期末報告初稿中，有部分待修正、釐清或進一步說明之處： (1)第3 頁文字中是圖1，圖卻是圖1-1 ，編號不一致；而有許多圖不清楚，建議重畫或抽換部分圖，例如圖2-1，圖2-7 為例，實在不夠清楚美觀；而圖上的文字說明也不清楚，例如圖2-4，建議全本報告徹底逐頁檢討圖內容及相關文字註記。第15 頁圖2-5 重複編列，第19 頁文指明圖2-9，	遵照辦理。

	但真正的圖2-9 卻與文字敘述內容兩回事，完全不相干；圖2-10也一樣，類似之處尚有不少，建議從頭到尾檢查一遍。 (2)第6 頁研究流程圖應該要有文字說明，不宜只有流程圖卻缺乏文字說明研究過程。 (3)第26 頁表3-1,至3-3 缺單位；29頁倒數第3 行「支」應該是「之」；圖表編列未依慣例依序出現，圖3-6 後就直接跳到圖3-12，表4-1表格內文字需重新排版。 (4)結論內容具體，但後續研究建議有突然結束而不完整感覺，只列出一項，但文字卻說「下列」，顯係尚未結束，有待補足或修改。 (5). 圖表編號文字大小比本文字體大，有違慣例，本文字體應大，圖表編號反而應小。 (6)本研究十分有實用參考價值，內容也具體，但排版實在該加強。	
本所陳組長瑞鈴		
8.1	本研究案之節能玻璃定義宜釐清，以免混淆。	有關本研究計畫主題之節能玻璃定義已於第一章第三節補充說明。
8.2	外牆清洗對室外側Low-E膜或隔熱膜耐久性影響程度為何？請補充說明。	已在第三章第四節中補充說明。

附件 3

Designation: G 7 – 97

Standard Practice for Atmospheric Environmental Exposure Testing of Nonmetallic Materials[1]

This standard is issued under the fixed designation G 7; the number immediately following the designation indicates the year of original adoption or, in the case of revision, the year of last revision. A number in parentheses indicates the year of last reapproval. A superscript epsilon (ε) indicates no editorial change since the last revision or reapproval.

1. Scope

1.1 This practice covers procedures to be followed for direct exposure of nonmetallic materials to the environment. When originators of a weathering test have the actual exposure conducted by a separate agency, the specific conditions for the exposure of test and control specimens should be clearly defined and mutually agreed upon between all parties.

1.2 For exposures behind glass, refer to Practice G 24.

1.3 The values stated in SI units are to be regarded as the standard. The inch-pound units given in parentheses are for information only.

1.4 This practice is technically equivalent to the parts of ISO 877 that describe direct exposures of specimens to the environment.

1.5 *This standard does not purport to address all of the safety concerns, if any, associated with its use. It is the responsibility of the user of this standard to establish appropriate safety and health practices and determine the applicability of regulatory limitations prior to use.*

2. Referenced Documents

2.1 *ASTM Standards:*

E 41 Terminology Relating to Conditioning[2]

E 824 Test Method for Transfer of Calibration from Reference to Field Pyranometers[3]

E 913 Test Method for Calibration of Reference Pyranometers with Axis Vertical by the Shading Method[3]

E 941 Test Method for Calibration of Reference Pyranometers with Axis Tilted by the Shading Method[3]

G 24 Practice for Conducting Exposures to Daylight Filtered Through Glass[2]

G 113 Terminology Relating to Natural and Artificial Weathering Tests of Nonmetallic Materials[2]

2.2 *ASTM Adjunct:*

Adjunct No. 12-700070-00 A Test Rack[4]

2.3 *ISO Standards:*

ISO 877 Plastics—Methods of Exposure to Direct Weathering; to Weathering Using Glass-Filtered Daylight, and to Intensified Weathering by Daylight Using Fresnel Mirrors[5]

3. Terminology

3.1 *Definitions*—The definitions given in Terminology E 41 and Terminology G 113 are applicable to this practice.

4. Significance and Use

4.1 The relative durability of materials in natural exposures can be very different depending on the location of the exposure because of differences in ultraviolet (UV) radiation, time of wetness, temperature, pollutants, and other factors. Therefore, it cannot be assumed that results from one exposure in a single location will be useful for determining relative durability in a different location. Exposures in several locations with different climates which represent a broad range of anticipated service conditions are recommended.

4.2 Because of year-to-year climatological variations, results from a single exposure test cannot be used to predict the absolute rate at which a material degrades. Several years of repeat exposures are needed to get an "average" test result for a given location.

4.3 Solar ultraviolet radiation varies considerably as a function of time of year. This can cause large differences in the apparent rate of degradation in many polymers. Comparing results for materials exposed for short periods (less than one year) is not recommended unless materials are exposed at the same time in the same location.

4.4 Defining exposure periods in terms of total solar or solar-ultraviolet radiant energy can reduce variability in results from separate exposures. Solar ultraviolet measurements may be made using instruments which record broadband UV (e.g. 295 ± 385 nm) or narrow band UV, as defined in Sections 7.2.4 and 7.2.5. An inherent limitation in solar-radiation measurements is that they do not reflect the effects of temperature and moisture, which are often as important as solar radiation.

4.5 The design of the exposure rack, the location of the specimen on the exposure rack, and the type or color of

[1] This practice is under the jurisdiction of ASTM Committee G-3 on Durability of Nonmetallic Materials and is the direct responsibility of Subcommittee G03.02 on Natural Environmental Testing.

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[2] *Annual Book of ASTM Standards*, Vol 14.02.

[3] *Annual Book of ASTM Standards*, Vol 12.02.

[4] Available from ASTM Headquarters, 100 Barr Harbor Dr., West Conshohocken, PA 19428. Request ADJG0007.

[5] Available from the American National Standards Institute (ANSI), 1430 Broadway, New York, NY 10018.

adjacent specimens can affect specimen temperature and time of wetness. In order to minimize variability caused by these factors, it is recommended that test specimens, control specimens, and any applicable weathering reference material be placed on a single test panel or on test panels placed adjacent to each other during exposure.

4.6 It is strongly recommended that at least one control material be part of any exposure evaluation. The control material should meet the requirements of Terminology G 113, and should be of similar composition and construction compared to test specimens. It is preferable to use two control materials, one with relatively good durability and one with relatively poor durability. Unless otherwise specified, use at least two replicate specimens of each test and control material being exposed. Control materials included as part of a test shall be used for the purpose of comparing the performance of test materials relative to the controls.

5. Test Sites, Location of Test Fixtures, and Exposure Orientation

5.1 *Test Sites*—Exposures can be conducted in any type of climate. However, in order to get more rapid indications of outdoor durability, exposures are often conducted in locations that receive high levels of solar radiation, temperature, and moisture. Typically, these conditions are found in hot desert and subtropical or tropical climates. Known attributes of the use environment should be represented by the locations selected for outdoor durability evaluation. For example, if the use environment for the product being evaluated will include freeze/thaw cycling, specimen exposure in a northern temperature climate is recommended. In addition, exposures are often conducted in areas where specimens are subjected to salt air (seashore) or industrial pollutants.

5.1.1 Unless otherwise specified, test fixtures or racks shall be located in cleared areas. The area beneath and in the vicinity of the test fixtures should be characterized by low reflectance and by ground cover typical of the climatological area where the exposures are being conducted. In desert areas, the ground is often gravel to control dust and in most temperate areas, the ground cover should be low-cut grass. The type of ground cover at the exposure site shall be indicated in the test report. If test fixtures are placed on a rooftop, specimens may be subjected to different environmental conditions than at ground level. These differences may affect test results.

5.2 The lowest row of specimens on a test fixture or rack shall be positioned at a height above the ground to avoid contact with vegetation and to prevent damage that might occur during area maintenance. A minimum height of 0.45 m (18 in.) above the ground is recommended.

5.3 Test fixtures shall be placed in a location so that there is no shadow on any specimen when the sun's angle of elevation is greater than 20°.

5.4 *Exposure Orientation*—Unless otherwise specified, exposure racks shall be oriented so that specimens face the equator. Specimens can be exposed at a number of different orientations or "exposure angles" in order to simulate end-use conditions of the material being evaluated. Typical exposure angles are as follows:

5.4.1 *Latitude Angle*—Exposure rack is positioned so that the exposed surface of specimens are at an angle from the horizontal that is equal to the geographical latitude of the exposure site.

5.4.2 *45°*—Exposure rack is positioned so that the exposed specimens are at an angle of 45° from the horizontal. This is the most commonly used exposure orientation.

5.4.3 *90°*—Exposure rack is positioned so that the exposed specimens are at an angle of 90° from the horizontal.

5.4.4 *5°*—Exposure rack is positioned so that the exposed specimens are at an angle of 5° from the horizontal. This angle is preferred over horizontal exposure to avoid standing water on specimens being exposed. This exposure angle typically receives the highest levels of solar radiation during midsummer and is used to test materials that would normally be used in horizontal or nearly horizontal applications.

NOTE 1—Exposures conducted at less than the site latitude typically receive more ultraviolet radiation than exposures conducted at larger angles.

5.4.5 Any other angle that is mutually agreed on by all interested parties may be used. In some instances, exposures facing directly away from the equator or some other specific direction may be desired. The test report shall contain the exact angle and specimen orientation of any exposure condition outside of those described in 5.4.1-5.4.4.

5.5 *Specimen Backing*—Three types of specimen backing can be used. Comparisons between materials should only be made with exposures conducted with the same specimen backing.

5.5.1 *Unbacked Exposures*—Specimens are exposed so that the portion of the test specimen being evaluated is subjected to the effects of the weather on all sides.

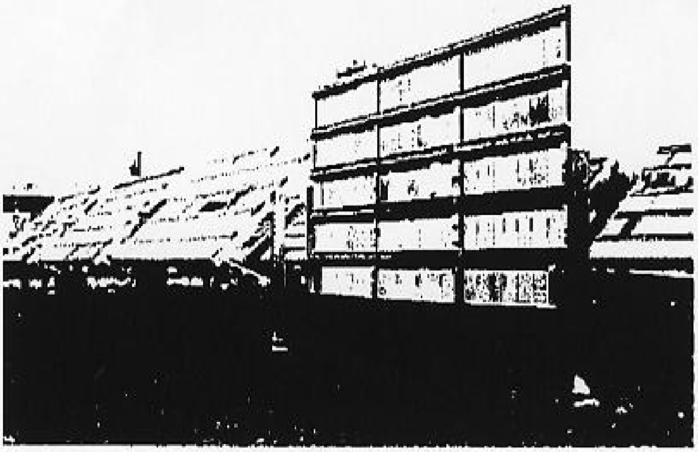
5.5.2 *Backed Exposures*—Specimens are attached to a solid substrate so that only the front surface is exposed. Surface temperatures of specimens in backed exposures will be higher than for specimens subjected to unbacked exposures. In some cases, the substrate is painted black, which produces significant differences in surface temperature compared to exposures conducted on unpainted substrate. This can cause large differences in degradation rates when compared to backed exposures conducted on unpainted substrates.

5.5.3 *Black Box Exposure*—Specimens are attached to the front face of a black painted aluminum box (see 6.2.3). The specimens form the top surface of the box. If there are not enough test specimens to completely cover the top surface, open areas shall be filled with black painted sheet metal panels so that the box is completely closed.

6. Construction of Test Fixtures (Exposure Racks)

6.1 *Materials of Construction*—All materials used for test fixtures shall be noncorrodible without surface treatment. Aluminum Alloys 6061T6 or 6063T6 have been found suitable for use in most locations. Properly primed and coated steel is suitable for use in desert areas. Monel has been found suitable in highly corrosive areas. Untreated wood is acceptable in desert areas but may pose maintenance problems in other areas. (See Fig. 1.)

6.1.1 For backed exposures (see 6.2.2 and Fig. 2), use exterior-grade plywood to form a solid surface to which



NOTE 1—Detailed drawings of this test rack may be obtained from ASTM Headquarters, 100 Barr Harbor Dr., W. Conshohocken, PA 19428. Request Adjunct No. 12-700070-00.

FIG. 1 Typical Exposure Rack

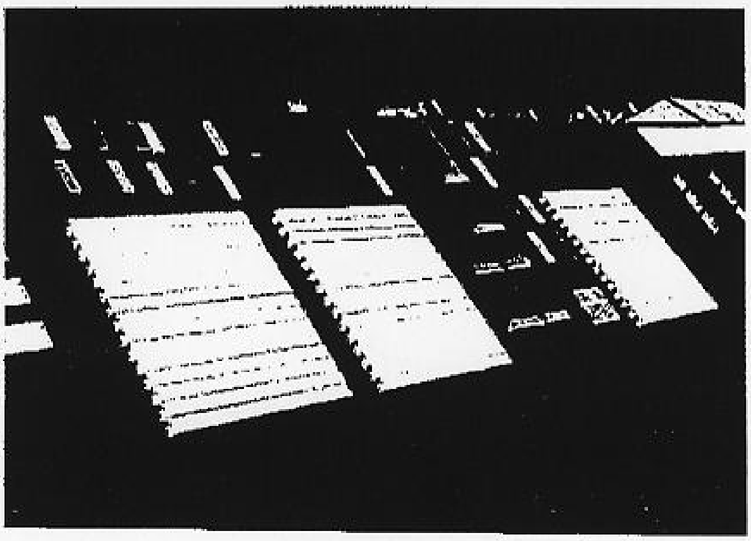


FIG. 2 Backed Exposure Rack

specimens are directly attached. Replace the plywood when there is any evidence of delamination or fiber separation. Medium-density overlay (MDO) or high-density overlay (HDO) plywood are satisfactory substrates and require less frequent replacement than plywood with no overlay. The edges of the plywood should be sealed with a durable paint to prevent delamination.

6.2 *Test Fixture Design*—Test racks shall be constructed to hold specimens or specimen holders of any convenient width

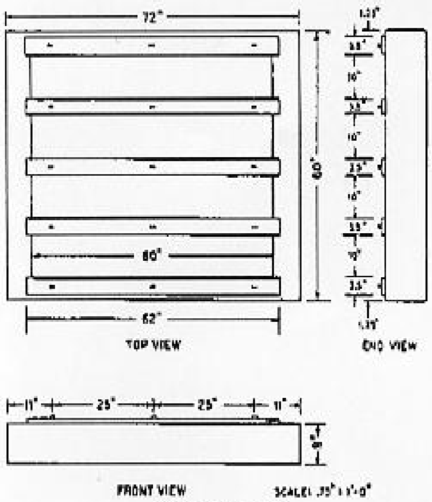


FIG. 3 Black Box

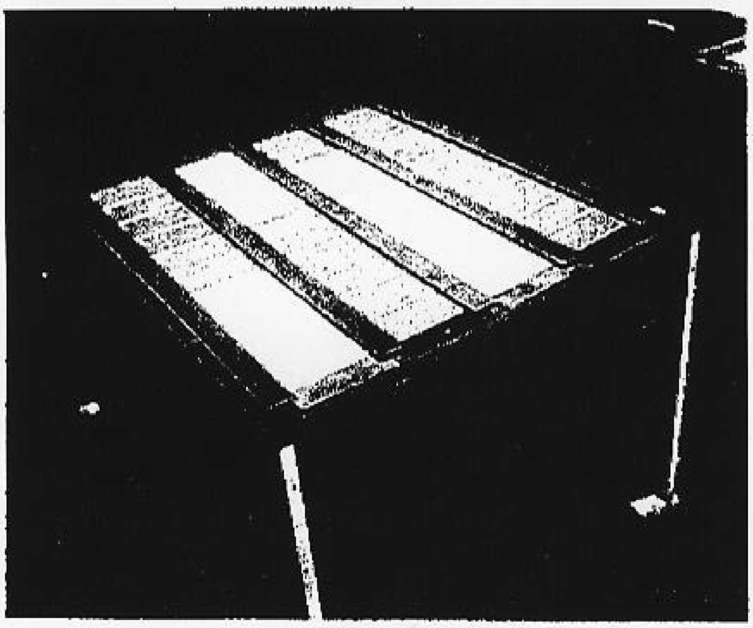


FIG. 4 Black Box In Use

and length. Racks shall be constructed so that any contamination from specimens higher on the fixture cannot run down onto specimens in lower positions. Test racks should be designed to provide backed or unbacked exposures, whichever best simulates end-use conditions.[6]

6.2.1 *Unbacked Exposures*—Test racks shall be constructed so that most of the test specimen is exposed to the effects of the weather on all sides. Specimens are attached to the test fixture at the top or bottom, or both, using clamping devices, properly spaced slots, or mechanical fasteners. The method of attachment shall not prevent expansion and contraction of specimens caused by temperature or moisture. Use fastening devices for attaching specimens to the test fixture that will not corrode or degrade and contaminate the specimens. Aluminum, properly galvanized steel, or stainless steel fasteners are recommended.

6.2.2 *Backed Exposures*—Test racks shall be constructed so that specimens are attached to a plywood substrate. The thickness of the plywood and type of coating used shall be agreed upon by all interested parties and must be reported.

NOTE 2—Backed exposures as described in this standard are not insulated exposures. For some applications such as outdoor exposure tests for roofing products, a layer of insulation material is attached behind the solid substrate to which specimens are attached. Insulated exposures of this type produce higher specimen temperatures than those that would be seen on backed exposures conducted according to this practice.

6.2.3 *Black Box Exposures*—An aluminum box 0.23 m (9 in.) deep with the outside surface painted black. The top surface is open and fitted with mounting strips to hold

[6] Detailed drawings for an acceptable test rack may be obtained from ASTM Headquarters. Request ADJG0007.

specimens firmly in place. Two types of black boxes are in common usage. One measures approximately 1.5 m (5 ft) high and 1.8 m (6 ft) wide and the other measures 1.7 m (5.5 ft) high and 3.7 m (12 ft) wide. Fig. 3 shows the design and dimensions for an acceptable black box. Fig. 4 shows a black box in use.

7. Instrumentation[7,8,9]

7.1 Instruments for determining climatological data during the exposure period should be operated in the immediate vicinity of the test racks. Data obtained shall be reported if requested as part of the results of a test.

7.2 Instruments for recording the following are recommended:

7.2.1 *Ambient Temperature (Daily Maximum and Minimum)*—Instruments used for recording ambient temperature shall be a thermocouple (Type T or J), a thermistor, or a resistance temperature device (RTD). Any instrument used shall have a calibration traceable to the National Institute for Standards and Technology (NIST) and must be calibrated no less often than every twelve months. Instruments shall be mounted inside a white ventilated enclosure.

7.2.2 *Relative Humidity (Daily Maximum and Minimum)*—Instruments used for recording relative humidity must have a calibration traceable to NIST. Instruments shall be mounted inside a white ventilated enclosure.

7.2.3 *Total Solar Radiation*—For measurement of total solar radiation, use a pyranometer meeting either WMO First Class or Second Class specification. Calibrate the pyranometer at the tilt-angle at which it will be used in suitable radiometric units. Calibrate the pyranometer against an instrument traceable to the WRR (World Radiometric Reference) at least annually. Perform this comparison either by comparison to a suitable reference pyranometer in accordance with Test Method E 824 or by the direct shading disk calibration in accordance with Test Method E 941 (for axis vertical and tilted respectively). If at tilt calibrations are not available, correct for tilt angle effects in accordance with the instructions provided by the radiometer manufacturer. If requested, a certificate of calibration shall be provided with all total solar irradiance measurements.

NOTE 3—Most radiometers are calibrated and sold as systems, complete with read out means which show appropriate units. In such cases radiometers are calibrated in Wm^{-2}. For radiometers without direct ready-out, calibration units should be $Wm^{-2}V^{-1}$.

7.2.4 *Total Solar Ultraviolet Radiation*— For measurement of total solar ultraviolet radiation, use a radiometer that measures ultraviolet radiation in the wavelength region from 300 to 385 nm. The total solar ultraviolet radiometer shall be calibrated against a standard source of spectral irradiance traceable to NIST, or other national standards laboratory, at least annually. The calibration shall be in suitable radiometric units, preferably in watts per square metre per volt ($Wm^{-2}V^{-1}$). If requested, a certificate of calibration shall be provided with all total solar ultraviolet irradiance measurements.

7.2.5 *Narrow-Band Solar Ultraviolet Radiation*—Narrowband radiometers can be used to measure specific wavelength bands of solar ultraviolet radiation. Unless otherwise specified, (for example, when measuring solar UV radiation with a wavelength greater than 315 nm), narrow-band UV radiometers shall, when used to time or monitor outdoor exposure testing, have response functions in the UV-B region defined as 280 to 315 nm. The narrow-band radiometers shall be calibrated against a standard source of spectral irradiance at least annually. The calibration shall be in suitable radiometric units, preferably in watts per square metre per volt ($Wm^{-2}V^{-1}$). If requested, a certificate of calibration shall be provided with all narrow band solar ultraviolet irradiance measurements.

8. Procedure

8.1 Prepare test specimens according to standards or procedures relevant to the materials being evaluated. Identify each specimen with a unique mark that will not be destroyed or become illegible during the exposure.

8.2 If nondestructive testing is used, measure the desired properties on all test and reference and control specimens prior to exposure. If destructive testing is done, measure the level of the desired property on a separate set of specimens. When destructive tests are used, separate sets of specimens are needed for each exposure period desired.

8.3 Select one of the following methods for defining the duration of exposure:

8.3.1 *Calendar Basis*—Expose specimens for a specified number of days, months, or years. The report shall indicate the exact dates of the exposure.

8.3.2 *Radiant Exposure Basis*—Expose specimens until a specified level of solar radiant exposure has been achieved. Use hemispherical radiation measurements (direct plus scattered solar radiation) as the basis for determining the radiant exposure. The wavelength region in which the solar energy is measured must be specified. The instruments used to measure radiant energy shall meet the requirements of 7.2.3-7.2.5. The report shall indicate the radiant energy, wavelength in which it was measured, and exact dates, if appropriate, of the exposure.

8.3.3 *Deterioration Basis*—Expose specimens until a specified physical change has occurred. Examples are degree of shrinkage, color change, blistering, gloss loss, or loss of strength. The report shall indicate the property used as a basis for defining the exposure, the method used to measure the property, the initial and final values of the desired property, and the exact dates of the exposure.

8.3.4 *Based on Property Change in Weathering Reference Material*—With this procedure, a weathering reference material shall be exposed with the test specimens. Expose until a specified change has occurred in the weathering reference material. The report shall describe the weathering reference material used, the property used as a basis for defining the exposure, the method used to measure the property, the initial and final values of the measured property of the weathering reference material, and the exact dates of the exposure.

[7] For further information on instrumentation, see either *Symposium on Weathering Conditioning, ASTM STP 133*, or Sereda, P. J.," Measurement of Surface Moisture," *ASTM Bulletin, No. 228*, 1959, pp. 61–63.

[8] *Guide to Meteorological Instruments and Methods of Observation*, 5th ed., WMO-No. 8, Secretariat of the World Meteorological Organization, Geneva, 1983.

[9] Suitable calibrations can usually be obtained from the manufacturer of the instrument.

REPORT FORM

Laboratory: ____
Material exposed: ____
Thickness of sample: ____ ;Backing on sample: ____ No ____ Yes ____
Type of backing: ____ ;Thickness: ____ ;"R" factor: ____
Coating on backing material ____
Reference Material Used-and-Backing on Material: ____
Exposure location: ____
Exposure starting date: ____ Exposure intervals: ____

Type of Exposure:	Wetness—Rain, h	Wetness—Rain and Dew, h	Temperature, °C		Solar Radiation	
			max	min	per interval	Total
Direct						
Behind glass						
Black box						
Sheltered						
Undercover						
Warehouse						
Special (indicate condition)						

Solar radiation measured by: ____

Mounting information on exposure: ____
Sample mounted on support (identify): ____
Height above ground: ____ in.; Ground cover: ____
Angle of exposure: ____ Direction: ____
Treatment of samples during exposure: ____ No: ____ Yes: ____
Treatment: ____
Frequency: ____
Mounting information on exposure:
Height above ground: ____ in.; Ground cover: ____
Angle of exposure: ____
Periodic cleaning of specimen: ____; Cycle: ____
How cleansed ____

FIG. 5 Suggested Report Form

9. Report

9.1 Report the following information with any reference to exposures conducted according the this practice:

9.1.1 Complete description of the test specimens and any control and weathering materials used, including:

9.1.1.1 Composition, including description of substrate to which specimens such as paints, coatings, graphic tapes, and so forth, are applied, and

9.1.1.2 Method of preparation (reference applicable standards here),

9.1.2 Location of exposure (including whether specimens were exposed at ground level, on a rooftop, and so forth),

9.1.3 Ground cover in area of test racks,

9.1.4 Angle at which exposure conducted,

9.1.5 Type of exposure (unbacked, backed, or black box). If backed exposure is used, include thickness and type of backing and, if painted, the color of paint used,

9.1.6 Date exposure started and date exposure completed,

9.1.7 If required, solar radiant exposure determined according to 7.2.3-7.2.5, including wavelength in which radiant energy measured. If required, include a certificate of calibration for the radiometer used, with this information, and

9.1.8 If used, details of any specimen treatment such as washing conducted during the exposure. This shall include description of the treatment used and the frequency of treatment.

9.1.9 If required, the following climate information:

9.1.9.1 Ambient temperature (daily maximum and minimum),

9.1.9.2 Relative humidity (daily maximum and minimum),

9.1.9.3 Total hours of wetness and method used to measure,

9.1.9.4 Rainfall in centimetres,

9.1.9.5 Concentration of pollutants such as NO_2, SO_2, O_3, and method used to measure the concentration, and

9.1.10 Results of property measurements if required or conducted before and after exposure. This shall include a description of the method used to measure the property.

10. Precision and Bias

10.1 *Precision:*

10.1.1 Repeatability and reproducibility of results obtained by this practice will vary depending on the materials being tested, the material property being measured, the climate in which the exposures are conducted, and year-to-year differences in climate at a single location. Therefore, no specific statement about the absolute precision of the results obtained by this practice can be made.

10.1.2 Because of the potentially high absolute variability in results obtained by this practice, performance requirements for materials tested according to this practice should be specified in terms of comparison with a control material. This control material shall be exposed simultaneously with the test specimen. The specific control material used must be agreed upon by all interested parties.

10.2 *Bias*—Bias in results obtained according to this practice will vary with the materials being tested, the material property being measured, the climate in which the exposures are conducted, and year-to-year differences in climate at a single location. In addition, no acceptable standard reference materials are available for the myriad of material weathering property responses.

11. Keywords

11.1 durability; exposure; weathering

Designation: G 24 – 97

AMERICAN SOCIETY FOR TESTING AND MATERIALS
100 Barr Harbor Dr., West Conshohocken, PA 19428

Standard Practice for Conducting Exposures to Daylight Filtered Through Glass[1]

This standard is issued under the fixed designation G 24; the number immediately following the designation indicates the year of original adoption or, in the case of revision, the year of last revision. A number in parentheses indicates the year of last reapproval. A superscript epsilon (ε) indicates an editorial change since the last revision or reapproval.

1. Scope

1.1 This practice evaluates the resistance of nonmetallic materials to solar radiation filtered through glass.

1.2 This practice is limited to the method of conducting the exposures. The preparation of test specimens and evaluation of results are covered in various standards for the specific materials.

1.3 Exposure conducted according to this practice can use two types of exposure cabinets.

1.3.1 *Type A*—A cabinet that allows passive ventilation of specimens being exposed behind glass.

1.3.2 *Type B*—Enclosed cabinet with exterior painted black that allows no ventilation of specimens exposed behind glass. Exposures conducted using a Type B cabinet are typically referred to as "black box under glass exposures".

1.4 This practice is technically similar to Method B of ISO 877.

1.5 *This standard does not purport to address all of the safety concerns, if any, associated with its use. It is the responsibility of the user of this standard to establish appropriate safety and health practices and determine the applicability of regulatory limitations prior to use.*

2. Referenced Documents

2.1 *ASTM Standards:*

E 782 Practice for Exposure of Cover Materials for Solar Collectors to Natural Weathering under Conditions Simulating Operational Mode[2]

E 824 Method for Transfer of Calibration from Reference to Field Pyranometers[2]

E 903 Test Method for Solar Absorptance, Reflectance, and Transmittance of Materials Using Integrating Spheres[2]

G 84 Practice for Measurement of Time-of-Wetness on Surfaces Exposed to Wetting Conditions as in Atmospheric Corrosion Testing[3]

G 113 Terminology Relating to Natural and Artificial Weathering Tests of Nonmetallic Materials[4]

2.2 *Other Documents:*

WMO Guide to Meteorological Instruments and Methods of Observation WMO No. 8, Fifth Edition.[5]

ISO 105 B01 Textiles—Tests for Colour Fastness, International Standards Organization, Geneva, Switzerland.[6]

ISO 877 Plastics—Methods of Exposure to Direct Weathering, to Weathering Using Glass-Filtered Daylight, and to Intensified Weathering by Daylight Using Fresnel Mirrors, International Standards Organization, Geneva, Switzerland[6]

AATCC 16C Colorfastness to Light, Daylight[7]

3. Terminology

3.1 *Definitions:*

3.1.1 The definitions contained in Terminology G 113 are applicable to this practice.

4. Significance and Use

4.1 Since solar irradiance, air temperature, relative humidity, and the amount and kind of atmospheric contaminants vary continuously, results from exposures based on time may differ. The variations in the results may be minimized by timing the exposures in terms of one or more environmental parameters such as solar radiant exposure, or in terms of a predetermined property change of a reference specimen with known performance.

4.2 Moisture combined with atmospheric contaminants may produce degradation effects as great as those produced by solar irradiance. This may explain differences in rankings of specimens exposed to equivalent solar radiant exposure when other environmental conditions vary.

4.3 Since the method of mounting may influence the temperature and other parameters of the specimen during exposure, there should be a mutual understanding as to the method of mounting the specimen for the particular exposure test under consideration.

4.4 There can be large differences in 300 to 350 nm UV transmission of single strength window glass. For example, at 320 nm, the percent transmission for seven different lots of single strength window glass ranged from 8.4 to 26.8 %. For

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[1] This practice is under the jurisdiction of ASTM Committee G-3 on Durability of Nonmetallic Materials and is the direct responsibility of Subcommittee G 03.02 on Natural Environmental Testing.

Current edition approved July 10, 1997. Published October 1997. Originally published as G 24 – 73. Last previous edition G 24 – 73 (1980).

[2] *Annual Book of ASTM Standards*, Vol 12.02.

[3] *Annual Book of ASTM Standards*, Vol 03.02.

[4] *Annual Book of ASTM Standards*, Vol 14.02.

[5] Available from World Meteorological Organization, Geneva, Switzerland.

[6] Available from American National Standards Institute, 11 W. 42nd St., 13th Floor, New York, NY 10036.

[7] American Association of Textile Chemists and Colorists, Research Triangle Park, PO Box 12215, NC 27709-2215.

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100 Barr Harbor Dr., West Conshohocken, PA 19428
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1.3.1 *Type A*—A cabinet that allows passive ventilation of specimens being exposed behind glass.

1.3.2 *Type B*—Enclosed cabinet with exterior painted black that allows no ventilation of specimens exposed behind glass. Exposures conducted using a Type B cabinet are typically referred to as "black box under glass exposures".

1.4 This practice is technically similar to Method B of ISO 877.

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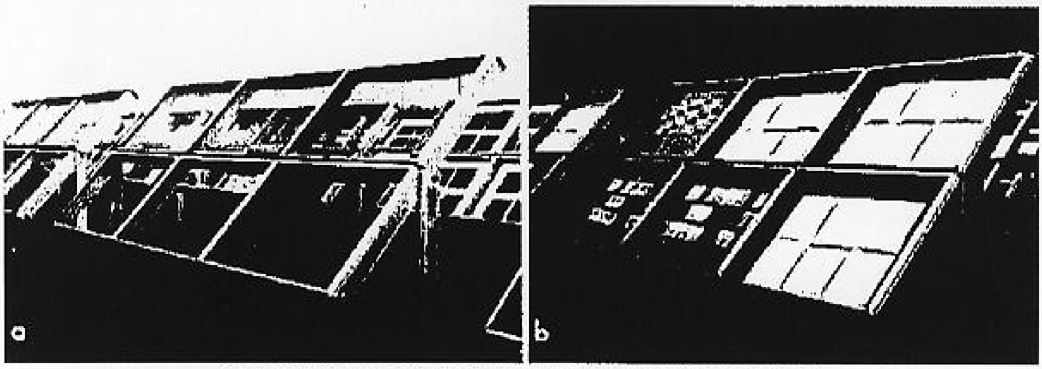

FIG. 1 a and 1b Typical Well-Ventilated Under Glass Exposure Cabinet, Type A

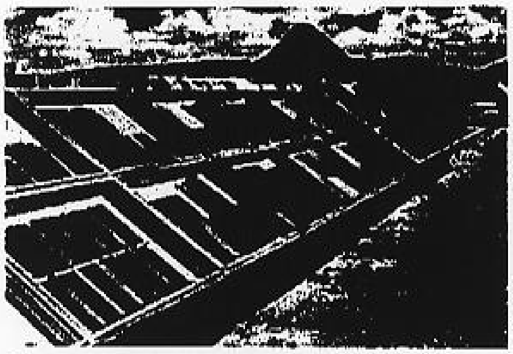

FIG. 2 Typical Enclosed Under Glass Exposure Cabinet, Type B (Black Box Under Glass)

this range of transmission, the rate of degradation for materials sensitive to short wavelength UV from 300 to 320 nm could vary by as much as 300 %.[8] In addition, exposures conducted at different times of the year can cause large differences in rate of degradation.[9]

4.5 In order to minimize differences in 300 to 340 nm UV transmission caused by rapid solarization of new glass, this practice requires that glass be pre-aged for three months prior to use in exposure cabinets.

4.6 Differences in UV transmission between different lots of glass persist after solarization.[8] The largest differences in UV transmission of glass are between 300 and 320 nm. Use of radiant exposure based on total solar radiation or total solar UV radiation to determine exposure periods is not sensitive to these differences. For materials very sensitive to differences in short wavelength UV radiation, monitoring UVB radiation behind glass may be the best approach for use when radiant energy is used to determine the length of exposures. However, for materials sensitive to long wavelength UV or visible radiation, monitoring UVB radiation or using reference materials that are very sensitive to short wavelength solar ultraviolet radiation to determine exposure periods may produce inconsistent results.

4.7 This practice is best used to compare the relative performance of materials tested at the same time behind the same lot of glass. Because of variability between lots of glass and between exposures conducted at different times of the year, comparing the amount of degradation in materials exposed for the same duration or radiant exposure at separate times, or in separate fixtures using different lots of glass is not recommended. This practice should not be used to establish "pass/fail" approval of materials after a specific period of exposure unless performance comparisons are made relative to a control material exposed simultaneously, or the variability in the test is quantified so that statistically significant pass/fail judgments can be made.

4.8 It is strongly recommended that at least one control material be exposed with each test. The control material should be of similar composition and construction and be chosen so that its degradation mechanisms or failure modes are the same as that of the material being tested. It is preferable to use two control materials, one with relatively good durability, and one with relatively poor durability. If control materials are included as part of the test, they shall be used for the purpose of comparing the performance of the test materials relative to the controls.

4.9 There are other standards which describe exposures to glass filtered daylight. Three cited standards are ISO 105-B01, ISO 877, and AATCC 16C.

4.10 Because of the possibility that certain materials may outgas during exposure, it is recommended that only similar materials be exposed in the same under glass cabinet.

5. Apparatus

5.1 *Exposure Cabinet*:

5.1.1 *Type A*—Exposures shall be conducted in a glass-covered enclosure or cabinet of any convenient size. It shall be constructed of wood, metal, or other satisfactory material, in

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[8] Ketola, W. D., and Robbins, J. S. "UV Transmission of Single Strength Window Glass", *Accelerated and Outdoor Durability Testing of Organic Materials, ASTM STP 1202*, Warren D. Ketola and Douglass Grossman, Eds, American Society for Testing and Materials, Philadelphia, 1993.

[9] Crewdson, L. F., and Bahadur-Singh, C., "A Review of the Variability Encountered When Exposure Materials to Glass Filtered Sunlight", *Accelerated and Outdoor Durability Testing of Organic Materials, ASTM STP 1202*, Warren D. Ketola and Douglass Grossman, Eds, American Society for Testing and Materials, Philadelphia, 1993.

order to protect the specimens from rain and weather, and shall be open on the back or sides to allow ambient air to circulate over the specimens (Fig. 1a and b).

5.1.2 *Type B (Black Box Under Glass)*—Exposures shall be conducted in a glass-covered enclosure or cabinet of any convenient size. It shall be constructed of corrosion resistant metal and be enclosed to prevent ambient air from circulating over specimens.[10] Exterior nonglass surfaces shall be painted flat black. The interior shall remain unpainted (Fig. 2).

NOTE 1—The black box under glass test method is often used to simulate under glass exposures under conditions of high temperature, such as the interior of an automobile. However, because black box under glass cabinets are enclosed, air temperatures may exceed 80°C under conditions of high outside ambient air temperature and solar irradiance. In addition, significant differences in air and specimen temperatures can be experienced between upper and lower portions of the cabinet. Frequent temperature measurement and specimen rotation may be required to properly use this test method.

5.1.3 Unless otherwise specified the glass cover shall be a piece of good grade, clear, flat-drawn sheet glass, free of bubbles or other imperfections. Typically, "single strength" glass, that is 2 to 2.5 mm thick, is used.

5.1.3.1 In order to reduce variability due to changes in UV transmission of glass, all new glass shall be exposed facing the equator, at the site latitude angle, according to Practice G 7, or on an empty under glass exposure cabinet, for at least three months prior to installation in test cabinets.

NOTE 2—Other standards describing exposures behind glass have different requirements for glass transmittance and do not require pre-aging.

5.1.3.2 After the three month pre-exposure period, it is recommended that the spectral transmittance of representative samples from each lot of glass be measured. Typically, "single strength" glass will have a transmittance of 10 to 20 % at 320 nm and at least 85 % at wavelengths of 380 nm or higher after the three month pre-aging procedure. If transmittance of the glass is measured, report the average for at least three pieces of the lot of glass being tested. Follow the instructions for measurement of transmittance of solid samples recommended by the manufacturer of the UV-visible spectrophotometer used. If a spectrophotometer with an integrating sphere is used, the measurements shall be performed in accordance with Test Method E 903.

NOTE 3—After the initial pre-aging period, the UV transmission of window glass is suitable for at least 60 months of use. UV transmission differences between lots of glass persist during this time, however.

5.1.3.3 Wash the exterior surface and the interior surface of the glass cover monthly (or more frequently, if required) to remove dust particles and other undesirable material.

NOTE 4—Different pieces of single-strength window glass can have different optical properties even if purchased from the same manufacturer.

5.1.4 The enclosure or cabinet shall be equipped with a rack which supports the specimens in a plane parallel to the glass cover at a distance of not less than 75 mm (3 in.). The mounting frame or plate shall be constructed of a material that is compatible with the test specimens. In order to minimize shadowing from the top and sides of the cabinet, the usable exposure area under the glass shall be limited to that of the glass cover reduced by twice the distance from the cover to the specimens. Three types of mounting frames or backings may be used.

5.1.4.1 *Unbacked or Open Mounting*—Specimens are attached only at edges.

5.1.4.2 *Expanded Aluminum Mounting*—Specimens are attached to an expanded aluminum backing.

5.1.4.3 *Solid Mounting*—Specimens are attached to a solid backing such as plywood.[11]

NOTE 5—The method used to mount specimens shall be related to their end-use. In evaluating the specimens, the edges of these specimens that are used to secure the specimen to the framework should be disregarded.

5.1.5 The cabinet shall be located where it will receive direct sunlight throughout the day and where shadows of objects in the vicinity will not fall upon it. When the cabinet is installed over soil, the distance between the bottom of the cabinet and the plane of the cleared area shall be a sufficient distance above ground to prevent possible undesirable effects of contact with plant growth, or to prevent damage during maintenance.

5.1.6 The glass cover and the test specimens shall be oriented in a manner mutually agreed upon between interested parties. The angle shall be reported in the results of the test. Possible exposure orientations are listed as follows:

5.1.6.1 Fixed tilt angle equal to the latitude of the exposure site with cabinet facing equator,

5.1.6.2 Tilt angle of 45° facing the equator,

5.1.6.3 Seasonally adjusted tilt angle with cabinet facing the equator (the tilt angles suggested by Practice E 782 may be used), and

5.1.6.4 Tracking azimuth and tilt angle in order to maintain the exposure plane normal to the sun's direct beam.

5.2 *Climatological Instruments*:

5.2.1 Instruments suitable for determining maximum, minimum, and average daily ambient air temperature, cabinet air temperature (optional), and specimen temperature (optional). Ambient air temperature will be measured in a shielded, elevated location in the general vicinity of the under glass exposure cabinet.

5.2.2 Instruments suitable for determining the maximum, minimum, and average daily ambient air humidity, and cabinet humidity (optional).

5.2.3 Instruments for recording solar radiant exposure under glass.

5.2.3.1 Instrumental means of measuring solar radiant exposure under glass shall consist of a pyranometer connected to an integrating device to indicate the total energy received over a given period. It shall be mounted under glass having the spectral transmittance characteristics specified in 5.1.3. The pyranometer shall be sensitive to solar irradiance received at a

[10] Suitable Cabinets meeting these requirements can be obtained from the William Harrison Company, Hinleah, FL.

[11] Exterior plywood having either a smooth paper finish on one side or covered with white cardboard such as Franklin, Grain long-felt side up, 110/500 white index, stock number 06506 or equivalent may be substituted.

geometry similar to that over which solar irradiance is received by the test specimens. The pyranometer shall be a World Meteorological Organization (WMO) Second Class instrument or better as defined by the WMO Guide to Meteorological Instruments.[12] The pyranometer shall be calibrated in accordance with Method E 824 no less often than annually against a WMO Secondary Standard pyranometer or a reference pyranometer whose calibration is traceable to the World Radiation Reference (WRR).[13]

5.2.3.2 Instrumental means of measuring solar radiant exposure in specific wavelength regions (such as all or a portion of the ultraviolet spectrum) shall consist of a wavelength-band specific global irradiance radiometer connected to an integrating device to indicate the energy received in a specified wavelength band over a given period (optional). The spectral response of the narrow-band radiometer shall be known and shall be as flat as possible throughout the spectral region utilized. It shall be mounted under glass having the spectral transmittance characteristics specified in 5.1.3.

NOTE 6—Solar radiant exposure should be measured and expressed in SI units of joules per square metre. One langley is equivalent to 4.184×10^4 J/m^2.

5.2.4 Instruments suitable for measuring time-of-wetness in accordance with Practice G 84 (optional). Time-of-wetness shall be measured in the same type of cabinet used for exposing the specimens.

6. Procedure

6.1 Unless otherwise specified, or agreed to by all interested parties, it is recommended that a minimum of three replicates of each material being tested be exposed. The simultaneous exposure of a similar number of specimens of a control is also strongly recommended.

6.2 Expose the test specimens, control specimens, and/or specimens of an applicable weathering reference material, (for example, blue wool) in the glass-covered exposure cabinet continuously 24 hours a day and remove from the cabinet only for inspection, return, or to protect specimens from possible damage during severe weather events.

6.3 Measure and record daily the maximum, minimum, and average air temperature and relative humidity in the vicinity of the test cabinet. It is also recommended that cabinet air temperature and humidities as well as specimen temperature be recorded.

NOTE 7—While these conditions cannot be controlled, a record of them is desirable to indicate the general conditions that prevailed during the exposure.

6.4 Remove the test specimens, control specimens, and/or specimens of applicable weathering reference material from the cabinet using one of the following procedures:

6.4.1 *Based on Amount of Solar Radiant Exposure*— Expose the test specimens for a specified solar radiant exposure dose, either total (all wavelengths) or a selected wavelength band. Report the results in terms of any specified method of measuring changes in test specimens.

6.4.2 *Based on Predetermined Property Change*—Expose the test specimens (and any specified reference specimen if desired) until a specified amount of property change has occurred in either the candidate materials or standard samples.

6.4.3 *Based on Duration of Exposure*—Expose the test specimens for a specified time period. Report the results in terms of any specified method of measuring changes in test specimens.

6.4.4 *Based on Any Other Specified Environmental Parameter*.

7. Report

7.1 The report shall include the following:

7.1.1 Type of exposure cabinet used, including the angle of the exposure rack. Report the transmittance characteristics of the glass, if measured. The wavelengths at which transmission is reported should be agreed upon by all interested parties.

7.1.2 Dates and location of exposure, including the latitude of the exposure site,

7.1.3 Applicable physical property or appearance data for each specimen obtained prior to exposure and after each exposure increment. If replicate specimens are used, report the mean and standard deviation of each property measured.

7.1.4 Methods used for measuring physical or appearance properties of test and control specimens.

7.1.5 Solar radiant exposure data expressed in SI units,

7.1.6 Maximum, minimum, and average daily temperatures, as well as cabinet air and specimen temperatures, if recorded,

7.1.7 Maximum, minimum, and average daily relative humidity, as well as cabinet humidity, if recorded,

7.1.8 Any other specified environmental parameter,

7.1.9 Any variations from the specified conditions, and

7.1.10 Type of specimen rack and mounting employed.

8. Keywords

8.1 aging; exposure; glass; ultraviolet; weathering

[12] Certain WMO Second Class pyranometers, notably those with segmented, black-and-white receivers (the so-called star pyranometers) have been found to exhibit significant deviations from the cosine law and significant tilt and temperature errors that are magnified by employment in glass-covered enclosures. They should only be employed when careful calibration tests have shown specific instruments to be free of such errors.

[13] Calibration certificates issued by the calibrating laboratory should state the chain of traceability to the WRR. If a pyranometer manufacturer is unable to meet this requirement for traceability, the calibration shall be performed by a nationally recognized calibration laboratory. Certified calibrations traceable to the WRR may be obtained from: The Eppley Laboratories, 12 Sheffield Ave., Newport, RI 02840; Heraeus DSET Laboratories, Inc., 45601 N. 47th Ave., Phoenix, AZ 85027-7042; and Environmental Research Laboratories, NOAA, 325 Broadway, Boulder, CO 80303.

Designation: G 152 – 06

Standard Practice for Operating Open Flame Carbon Arc Light Apparatus for Exposure of Nonmetallic Materials[1]

This standard is issued under the fixed designation G 152; the number immediately following the designation indicates the year of original adoption or, in the case of revision, the year of last revision. A number in parentheses indicates the year of last reapproval. A superscript epsilon (ε) indicates an editorial change since the last revision or reapproval.

1. Scope

1.1 This practice covers the basic principles and operating procedures for using open flame carbon-arc light and water apparatus intended to reproduce the weathering effects that occur when materials are exposed to sunlight (either direct or through window glass) and moisture as rain or dew in actual use. This practice is limited to the procedures for obtaining, measuring, and controlling conditions of exposure. A number of exposure procedures are listed in an appendix; however, this practice does not specify the exposure conditions best suited for the material to be tested.

NOTE 1—Practice G 151 describes performance criteria for all exposure devices that use laboratory light sources. This practice replaces Practice G 23, which describes very specific designs for devices used for carbon-arc exposures. The apparatus described in Practice G 23 is covered by this practice.

1.2 Test specimens are exposed to filtered open flame carbon arc light under controlled environmental conditions. Different filters are described.

1.3 Specimen preparation and evaluation of the results are covered in methods or specifications for specific materials. General guidance is given in Practice G 151 and ISO 4892-1. More specific information about methods for determining the change in properties after exposure and reporting these results is described in Practice D 5870.

1.4 The values stated in SI units are to be regarded as the standard.

1.5 *This standard does not purport to address all of the safety concerns, if any, associated with its use. It is the responsibility of the user of this standard to establish appropriate safety and health practices and determine the applicability of regulatory limitations prior to use.*

1.5.1 Should any ozone be generated from the operation of the light source, it shall be carried away from the test specimens and operating personnel by an exhaust system.

1.6 This practice is technically similar to ISO 4892-4.

2. Referenced Documents

2.1 *ASTM Standards:* [2]

D 3980 Practice for Interlaboratory Testing of Paint and Related Materials[3]

D 5870 Practice for Calculating Property Retention Index of Plastics

E 691 Practice for Conducting an Interlaboratory Study to Determine the Precision of a Test Method

G 23 Practice for Operating Light-Exposure Apparatus (Carbon-Arc Type) With and Without Water for Exposure of Nonmetallic Materials[3]

G 113 Terminology Relating to Natural and Artificial Weathering Tests of Nonmetallic Materials

G 151 Practice for Exposing Nonmetallic Materials in Accelerated Test Devices that Use Laboratory Light Sources

2.2 *CIE Standard:*

CIE-*Publ.* No. 85: Recommendations for the Integrated Irradiance and the Spectral Distribution of Simulated Solar Radiation for Testing Purposes[4]

2.3 *ISO Standards:*

ISO 4892-1, Plastics—Methods of Exposure to Laboratory Light Sources, Part 1, General Guidance[4]

ISO 4892-4, Plastics—Methods of Exposure to Laboratory Light Sources, Part 4, Open-Flame Carbon Arc Lamp[4]

3. Terminology

3.1 *Definitions*—The definitions given in Terminology G 113 are applicable to this practice.

3.1.1 As used in this practice, the term *sunlight* is identical to the terms *daylight* and *solar irradiance, global* as they are defined in Terminology G 113.

4. Summary of Practice

4.1 Specimens are exposed to repetitive cycles of light and moisture under controlled environmental conditions.

[1] This practice is under the jurisdiction of ASTM Committee G03 on Weathering and Durability and is the direct responsibility of Subcommittee G03.03 on Simulated and Controlled Exposure Tests.

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[2] For referenced ASTM standards, visit the ASTM website, www.astm.org, or contact ASTM Customer Service at service@astm.org. For *Annual Book of ASTM Standards* volume information, refer to the standard's Document Summary page on the ASTM website.

[3] Withdrawn.

[4] Available from American National Standards Institute, 25 W. 43rd St., 4th Floor, New York, NY 10036.

4.1.1 Moisture usually is produced by spraying the test specimen with demineralized/deionized water or by condensation of water vapor onto the specimen.

4.2 The exposure condition may be varied by selection of:

4.2.1 Light source filter,

4.2.2 The type of moisture exposure,

4.2.3 The timing of the light and moisture exposure,

4.2.4 The temperature of light exposure, and

4.2.5 The timing of a light/dark cycle.

4.3 Comparison of results obtained from specimens exposed in same model of apparatus should not be made unless reproducibility has been established among devices for the material to be tested.

4.4 Comparison of results obtained from specimens exposed in different models of apparatus should not be made unless correlation has been established among devices for the material to be tested.

5. Significance and Use

5.1 The use of this apparatus is intended to induce property changes associated with the end use conditions, including the effects of sunlight, moisture, and heat. These exposures may include a means to introduce moisture to the test specimen. Exposures are not intended to simulate the deterioration caused by localized weather phenomena, such as atmospheric pollution, biological attack, and saltwater exposure. Alternatively, the exposure may simulate the effects of sunlight through window glass. Typically, these exposures would include moisture in the form of humidity.

5.2 *Cautions*—Refer to Practice G 151 for full cautionary guidance applicable to all laboratory weathering devices. Variation in results may be expected when operating conditions are varied within the accepted limits of this practice. No reference, therefore, shall be made to results from the use of this practice unless accompanied by a report detailing the specific operating conditions in conformance with Section 10. It is recommended that a similar material of known performance, a control, be exposed simultaneously with the test specimen to provide a standard for comparative purposes. It is recommended that at least three replicates of each material evaluated be exposed in each test to allow for statistical evaluation of results.

6. Apparatus

6.1 *Laboratory Light Source*—Open flame carbon arc light sources typically use three or four pairs of carbon rods, which contain a mixture of rare-earth metal salts and have a metal coating such as copper on the surface. An electric current is passed between the carbon rods which burn and give off ultraviolet, visible, and infrared radiation. The carbon rod pairs are burned in sequence, with one pair burning at any one time. Use carbon rods recommended by the device manufacturer.

6.1.1 *Filter Types*—Radiation emitted by the open flame carbon arc contains significant levels of very short wavelength UV (less than 260 nm) and must be filtered. Two types of glass filters are commonly used. Other filters may be used by mutual agreement by the interested parties as long as the filter type is reported in conformance with the report section in Practice G 151.

6.1.2 None of these filters changes the spectral power distribution of the open flame carbon arc to make it match daylight in the long wavelength UV or the visible light regions of the spectrum.

6.1.3 The following factors can affect the spectral power distribution of open flame carbon arc light sources:

6.1.3.1 Differences in the composition and thickness of filters can have large effects on the amount of short wavelength UV radiation transmitted.

6.1.3.2 Aging of filters can result in changes in filter transmission. The aging properties of filters can be influenced by the composition. Aging of filters can result in a significant reduction in the short wavelength UV emission of a burner.

6.1.3.3 Accumulation of dirt or other residue on filters can affect filter transmission.

6.1.3.4 Differences in the composition of the metallic salts used in he carbon rods can affect the spectral power distribution.

6.1.4 *Spectral Irradiance*:

6.1.4.1 *Spectral Irradiance of Open Flame Carbon Arc with Daylight Filters*—Daylight filters are used to reduce the short wavelength UV irradiance of the open flame carbon arc in an attempt to provide simulation of the short wavelength UV region of daylight. [5]The data in Table 1 is representative of the

[5] Fischer, R., Ketola, W., Murray, W., "Inherent Variability in Accelerated Weathering Devices," *Progress in Organic Coatings*, Vol 19 (1991), pp. 165–179.

TABLE 1 Typical Relative Ultraviolet Spectral Power Distribution of Open-Flame Carbon-Arc with Daylight Filters[A,B]

Spectral Bandpass Wavelength λ in nm	Typical Percent[C]	Benchmark Solar Radiation Percent[D,E,F]
λ < 290		
290 ≤ λ ≤ 320	2.9	5.8
320 < λ ≤ 360	20.4	40.0
360 < λ ≤ 400	76.7	54.2

[A] Data in Table 1 are the irradiance in the given bandpass expressed as a percentage of the total irradiance from 290 to 400 nm. Annex A1 states how to determine relative spectral irradiance.

[B] The data in Table 1 is representative and is based on the rectangular integration of the spectral power distributions of open flame carbon arcs with daylight filters. There is not enough data available to establish a meaningful specification.

[C] For any individual spectral power distribution, the calculated percentage for the bandpasses in Table 1 will sum to 100 %. Test results can be expected to differ between exposures using open flame carbon arc devices in which the spectral power distributions differ by as much as that allowed by the tolerances typical for daylight filters. Contact the manufacturer of the carbon-arc devices for specific spectral power distribution data for the open flame carbon-arc and filters used.

[D] The benchmark solar radiation data is defined in ASTM G 177 and is for atmospheric conditions and altitude chosen to maximize the fraction of short wavelength solar UV. While this data is provided for comparison purposes only, a laboratory accelerated light source with daylight filters to provide a spectrum that is a close match to this the benchmark solar spectrum.

[E] Previous versions of this standard used solar radiation data from Table 4 of CIE Publication number 85. See Appendix X2 for more information comparing the solar radiation data used in this standard with that for CIE 85, Table 4.

[F] For the benchmark solar spectrum, the UV irradiance (290-400 nm) is 9.8 % and the visible irradiance (400-800 nm) is 90.2 % expressed as a percentage of the total irradiance from 290 to 800 nm. The percentages of UV and visible irradiances on samples exposed in open flame carbon-arc devices may vary due to the number and reflectance properties of specimens being exposed. This is based on measurements in xenon-arc devices but similar measurements have not been made in open flame carbon-arc devices.

spectral irradiance received by a test specimen mounted in the specimen plane of an open flame carbon arc equipped with daylight filters.

NOTE 2—The typical spectral irradiance for open-flame carbon arc with daylight filters was obtained using a borosilicate glass filter.

6.1.4.2 *Spectral Irradiance of Open Flame Carbon Arc With Window Glass Filters*—Window glass filters use a heat resistant glass to filter the open flame carbon arc in a simulation of sunlight filtered through single strength window glass.[6] The data in Table 2 is representative of the spectral irradiance received by a test specimen mounted in the specimen plane of an open flame carbon arc equipped with window glass filters.

6.1.4.3 *Spectral Irradiance of Open Flame Carbon arc With Extended UV filters* —Filters that transmit more short wavelength UV are sometimes used to accelerate test results. Although this type of filter has been specified in many tests because of historical precedent, they transmit significant radiant energy below 300 nm (the typical cut-on wavelength for terrestrial sunlight) and may result in aging processes not occurring outdoors.[5] The spectral irradiance for an open flame carbon arc with extended UV filters shall comply with the requirements of Table 3.

[6] Ketola, W., Robbins, J. S., "UV Transmission of Single Strength Window Glass," *Accelerated and Outdoor Durability Testing of Organic Materials, ASTM STP 1202*, Warren D. Ketola and Douglas Grossman, Eds., American Society for Testing and Materials, Philadelphia, 1993.

TABLE 2 Typical Relative Spectral Power Distribution for Open Flame Carbon Arc With Window Glass Filters (Representative Data)

Ultraviolet Wavelength Region
Irradiance as a Percentage of Total Irradiance from 300 to 400 nm

Bandpass (nm)	Open Flame Carbon Arc with Window Glass Filters^A	Estimated Window Glass Filtered Sunlight^B
250–270	0 %	0 %
271–290	0 %	0 %
291–300	0 %	0 %
301–320	2.1 %	0.1–1.5 %
321–340	8.1 %	9.4–14.8 %
341–360	13.2 %	23.2–23.5 %
361–380	27.3 %	29.6–32.5 %
381–400	49.3 %	30.9–34.5 %

Ultraviolet and Visible Wavelength Region Irradiance as a Percentage of Total Irradiance from 300 to 800 nm^C
Irradiance as a Percentage of Total Irradiance from 300 to 800 nm^C

Bandpass (nm)	Open Flame Carbon Arc with Window Glass Filters^E	Estimated Window Glass Filtered Sunlight^D
300–400	22.7–34.1 %	9.0–11.1 %
401–700	51.1–67.3 %	71.3–73.1 %

*Data from 701 to 800 nm is not shown

^{A}*Carbon Arc Data*—This data are for a typical spectral power distribution for an open flame carbons arc with window glass filters. Not enough spectral data is available for meaningful analysis to develop a specification. Subcommittee G03.03 is working to collect sufficient data in order to develop a specification.

^{B}*Sunlight Data*—The sunlight data is for global irradiance on a horizontal surface with an air mass of 1.2, column ozone 0.294 atm cm, 30 % relative humidity, altitude 2100 m (atmospheric pressure of 787.8 mb), and an aerosol represented by an optical thickness of 0.081 at 300 nm and 0.62 at 400 nm. The range is determined by multiplying solar irradiance by the upper and lower limits for transmission of single strength window glass samples used for studies conducted by Subcommittee G03.02.[6]

^{C}*Sunlight Data*—The sunlight data is from Table 4 of CIE Publication No. 85, global solar irradiance on a horizontal surface with an air mass of 1.0, column ozone of 0.34 atm cm, 1.42 cm precipitable water vapor, and an aerosol represented by an optical thickness of 0.1 at 500 nm.

TABLE 3 Relative Spectral Power Distribution for Open Flame Carbon-Arc with Extended UV Filters^{A,B}

Spectral Bandpass Wavelength λ in nm	Minimum Percent^C	Benchmark Solar Radiation – Percent^{D,E,F}	Maximum Percent^C
λ < 290			4.9
290 ≤ λ ≤ 320	2.3	5.8	6.7
320 < λ ≤ 360	16.4	40.0	24.3
360 < λ ≤ 400	68.1	54.2	80.1

^{A}Data in Table 3 are the irradiance in the given bandpass expressed as a percentage of the total irradiance from 250 to 400 nm. The manufacturer is responsible for determining conformance to Table 3. Annex A1 states how to determine relative spectral irradiance.

^{B}The data in Table 3 are based on the rectangular integration of 24 spectral power distributions for open flame carbon-arcs with various lots of carbon rods and extended UV filters of various lots and ages. The spectral power distribution data is for filters within the aging recommendations of the device manufacturer. The minimum and maximum data are at least the three sigma limits from the mean for all measurements.

^{C}For any individual spectral power distribution, the calculated percentage for the bandpasses in Table 1 will sum to 100 %. Test results can be expected to differ between exposures using open flame carbon arc devices in which the spectral power distributions differ by as much as that allowed by the tolerances typical for daylight filters. Contact the manufacturer of the carbon-arc devices for specific spectral power distribution data for the open flame carbon-arc and filters used.

^{D}The ASTM benchmark solar radiation data is defined in ASTM G 177 and is for atmospheric conditions and altitude chosen to maximize the short wavelength UV fraction of solar UV. This data is provided for comparison purposes only.

^{E}Previous versions of this standard used solar radiation data from Table 4 of CIE Publication Number 85. See Appendix X2 for more information comparing the solar radiation data used in the standard with that for CIE 85 Table 4.

^{F}For the benchmark solar spectrum, the UV irradiance (290-400 nm) is 9.8% and the visible irradiance (400-800 nm) is 90.2% expressed as a percentage of the total irradiance from 290 to 800 nm. The percentages of UV and visible irradiances on samples exposed in filtered open flame carbon arc devices may vary due to the number and reflectance properties of specimens being exposed. This is based on measurements in xenon-arc devices but similar measurements have not been made in open flame carbon-arc devices.

NOTE 3—The most commonly used type of extended UV filters are made from Potash-Lithia glass and are commonly known as Corex D filters.

6.2 *Test Chamber*—The design of the test chamber may vary, but it should be constructed from corrosion resistant material, and in addition to the radiation source, may provide for means of controlling temperature and relative humidity. When required, provision shall be made for the spraying of water on the test specimen or for the formation of condensate on the exposed face of the specimen.

6.2.1 The radiant source(s) shall be located with respect to the specimens such that the irradiance at the specimen face complies with the requirements in Practice G 151.

6.3 *Instrument Calibration*—To ensure standardization and accuracy, the instruments associated with the exposure apparatus, for example, timers, thermometers, wet bulb sensors, dry bulb sensors, humidity sensors, UV sensors, radiometers, require periodic calibration to ensure repeatability of test results. Whenever possible, calibration should be traceable to national or international standards. Calibration schedule and procedure should be in accordance with manufacturer's instructions.

6.4 *Thermometer*—Either insulated or uninsulated black or white panel thermometers may be used. Thermometers shall conform to the descriptions found in Practice G 151. The type of thermometer used, the method of mounting on specimen holder, and the exposure temperature shall be stated in the test report.

6.4.1 The thermometer shall be mounted on the specimen rack so that its surface is in the same relative position and subjected to the same influences as the test specimens.

6.4.2 Some specifications may require chamber air temperature control. Positioning and calibration of chamber air temperature sensors shall be in accordance with the descriptions found in Practice G 151.

NOTE 4—Typically, these devices control by black panel temperature only.

6.5 *Moisture*—The test specimens may be exposed to moisture in the form of water spray, condensation, or high humidity.

6.5.1 *Water Spray*—The test chamber may be equipped with a means to introduce intermittent water spray onto the front or the back of the test specimens, under specified conditions. The spray shall be applied so that the specimens are uniformly wetted. The spray system shall be made from corrosion resistant materials that do not contaminate the water used.

6.5.1.1 *Spray Water Quality*—Spray water must have a conductivity below 5 μS/cm, contain less than 1-ppm solids, and leave no observable stains or deposits on the specimens. Very low levels of silica in spray water can cause significant deposits on the surface of test specimens. Care should be taken to keep silica levels below 0.1 ppm. In addition to distillation, a combination of deionization and reverse osmosis can effectively produce water of the required quality. The pH of the water used should be reported. See Practice G 151 for detailed water quality instructions.

6.5.2 *Condensation*—A spray system designed to cool the specimen by spraying the back surface of the specimen or specimen substrate may be required when the exposure program specifies periods of condensation.

6.5.3 *Relative Humidity*—The test chamber may be equipped with a means to measure and control the relative humidity. Such instruments shall be shielded from the light source radiation.

6.6 *Specimen Holders*—Holders for test specimens shall be made from corrosion resistant materials that will not affect the test results. Corrosion resistant alloys of aluminum or stainless steel have been found acceptable. Brass, steel, or copper shall not be used in the vicinity of the test specimens.

6.6.1 The specimen holders typically, but not necessarily, are mounted on a revolving cylindrical rack which is rotated around the light source at a speed dependent on the type of equipment and which is centered both horizontally and vertically with respect to the exposure area in the specimen holders.

6.6.2 Specimen holders may be in the form of an open frame, leaving the back of the specimen exposed, or they may provide the specimen with a solid backing. Any backing used may affect test results and shall be agreed upon in advance between the interested parties.

6.7 *Apparatus to Assess Changes in Properties*—Use the apparatus required by the ASTM or other standard that describes determination of the property or properties being monitored.

7. Test Specimen

7.1 Refer to Practice G 151.

8. Test Conditions

8.1 Any exposure conditions may be used, as long as the exact conditions are detailed in the report. Appendix X1 lists some representative exposure conditions. These are not necessarily preferred and no recommendation is implied. These conditions are provided for reference only.

9. Procedure

9.1 Identify each test specimen by suitable indelible marking, but not on areas to be used in testing.

9.2 Determine which property of the test specimens will be evaluated. Prior to exposing the specimens, quantify the appropriate properties in accordance with recognized ASTM or international standards. If required, for example, destructive testing, use unexposed file specimens to quantify the property. See Practice D 5870, for detailed guidance.

9.3 *Mounting of Test Specimens*—Attach the specimens to the specimen holders in the equipment in such a manner that this specimens are not subject to any applied stress. To assure uniform exposure conditions, fill all of the spaces, using blank panels of corrosion resistant material if necessary.

NOTE 5—Evaluation of color and appearance changes of exposed materials must be made based on comparisons to unexposed specimens of the same material, which have been stored in the dark. Masking or shielding the face of test specimens with an opaque cover for the purpose of showing the effects of exposure on one panel is not recommended. Misleading results may be obtained by this method, since the masked portion of the specimen is still exposed to temperature and humidity that in many cases will affect results.

9.4 *Exposure to Test Conditions*—Program the selected test conditions to operate continuously throughout the required number of repetitive cycles. Maintain these conditions throughout the exposure. Interruptions to service the apparatus and to inspect specimens shall be minimized.

9.5 *Specimen Repositioning*—Periodic repositioning of the specimens during exposure is not necessary if the irradiance at the positions farthest from the center of the specimen area is at least 90 % of that measured at the center of the exposure area. Irradiance uniformity shall be determined in accordance with Practice G 151.

9.5.1 If irradiance at positions farthest from the center of the exposure area is between 70 and 90 % of that measured at the center, one of the following three techniques shall be used for specimen placement.

9.5.1.1 Periodically reposition specimens during the exposure period to ensure that each receives an equal amount of radiant exposure. The repositioning schedule shall be agreed upon by all interested parties.

9.5.1.2 Place specimens only in the exposure area where the irradiance is at least 90 % of the maximum irradiance.

9.5.1.3 To compensate for test variability, randomly position replicate specimens within the exposure area which meets the irradiance uniformity requirements as defined in 9.5.1.

9.6 *Inspection*—If it is necessary to remove a test specimen for periodic inspection, take care not to handle or disturb the test surface. After inspection, the test specimen shall be returned to the test chamber with its test surface in the same orientation as previously tested.

9.7 *Apparatus Maintenance*—The test apparatus requires periodic maintenance to maintain uniform exposure conditions. Perform required maintenance and calibration in accordance with manufacturer's instructions.

9.8 Expose the test specimens for the specified period of exposure. See Practice G 151 for further guidance.

9.9 At the end of the exposure, quantify the appropriate properties in accordance with recognized ASTM or international standards and report the results in conformance with Practice G 151.

NOTE 6—Periods of exposure and evaluation of test results are addressed in Practice G 151.

10. Test Report

10.1 The test report shall conform to Practice G 151.

11. Precision and Bias

11.1 *Precision:*

11.1.1 The repeatability and reproducibility of results obtained in exposures conducted according to this practice will vary with the materials being tested, the material property being measured, and the specific test conditions and cycles that are used. In round-robin studies conducted by Subcommittee G03.03, the 60° gloss values of replicate PVC tape specimens exposed in different laboratories using identical test devices and exposure cycles showed significant variability.[7] The variability shown in these round-robin studies restricts the use of absolute specifications, such as requiring a specific property level after a specific exposure period.

11.1.2 If a standard or specification for general use requires a definite property level after a specific time or radiant exposure in an exposure test conducted according to this practice, the specified property level shall be based on results obtained in a round-robin that takes into consideration the variability due to the exposure and the test method used to measure the property of interest. The round-robin shall be conducted according to Practices D 3980 or E 691 and shall include a statistically representative sample of all laboratories or organizations who normally would conduct the exposure and property measurement.

11.1.3 If a standard or specification for use between two or three parties requires a definite property level after a specific time or radiant exposure in an exposure test conducted according to this practice, the specified property level shall be based on statistical analysis of results from at least two separate, independent exposures in each laboratory. The design of the experiment used to determine the specification shall take into consideration the variability due to the exposure and the test method used to measure the property of interest.

11.1.4 The round-robin studies cited in 11.1.1 demonstrate that the gloss values for a series of materials could be ranked with a high level of reproducibility between laboratories. When reproducibility in results from an exposure test conducted according to this practice have not been established through round-robin testing, performance requirements for materials shall be specified in terms of comparison (ranked) to a control material. The control specimens shall be exposed simultaneously with the test specimen(s) in the same device. The specific control material used shall be agreed upon by the concerned parties. Expose replicates of the test specimen and the control specimen so that statistically significant performance differences can be determined.

11.2 *Bias*—Bias cannot be determined because no acceptable standard weathering reference materials are available.

12. Keywords

12.1 accelerated; accelerated weathering; carbon arc; durability; exposure; laboratory weathering; light; lightfastness; nonmetallic materials; open flame carbon arc; sunshine carbon arc; temperature; ultraviolet; weathering

[7] Fischer, R. M., "Results of Round-Robin Studies of Light- and Water-Exposure Standard Practices," *Symposium on Accelerated and Outdoor Durability Testing of Organic Materials, ASTM STP 1202*, Warren K. Ketola and Douglas Grossman, Editors, ASTM, 1993.

ANNEX

A1. DETERMINING CONFORMANCE TO SPECTRAL POWER DISTRIBUTION TABLES

(Mandatory Information for Equipment Manufacturers)

A1.1 Conformance to the spectral power distribution tables is a design parameter for an open flame carbon-arc with the different filters provided. Manufacturers of equipment claiming conformance to this standard shall determine conformance to the spectral power distribution tables for all carbon-arc/filter combinations provided, and provide information on maintenance procedures to minimize any spectral changes that may occur during normal use.

A1.2 The spectral power distribution data for this standard were developed using the rectangular integration technique. Eq A1.1 is used to determine the relative spectral irradiance using rectangular integration. Other integration techniques can be used to evaluate spectral power distribution data, but may give different results. When comparing spectral power distribution data to the spectral power distribution requirements of this standard, use the rectangular integration technique.

A1.3 To determine whether a specific filter for an open flame carbon-arc device meets the requirements of Table 1, Table 2, or Table 3, measure the spectral power distribution from 250 nm to 400 nm. Typically, this is done at 2 nm increments. If the manufacturer's spectral measurement equipment cannot measure wavelengths as low as 250 nm, the lowest measurement wavelength must be reported. The lowest wavelength measured shall be no greater than 270 nm. For determining conformance to the relative spectral irradiance requirements for an open flame carbon-arc with extended UV filters, measurement from 250 nm to 400 nm is required. The total irradiance in each wavelength bandpass is then summed and divided by the specified total UV irradiance according to Eq A1.1. Use of this equation requires that each spectral interval must be the same (for example, 2 nm) throughout the spectral region used.

$$I_R = \frac{\sum_{\lambda_i = A}^{\lambda_i = B} E_{\lambda_i}}{\sum_{\lambda_i = C}^{\lambda_i = 400} E_{\lambda_i}} \times 100 \qquad (A1.1)$$

where:

I_R = relative irradiance in percent,
E = irradiance at wavelength λ_i (irradiance steps must be equal for all bandpasses),
A = lower wavelength of wavelength bandpass,
B = upper wavelength of wavelength bandpass,
C = lower wavelength of total UV bandpass used for calculating relative spectral irradiance (290 nm for daylight filters, 300 nm for window glass filters, or 250 nm for extended UV filters), and
λ_i = wavelength at which irradiance was measured.

APPENDIXES

(Nonmandatory Information)

X1. EXPOSURE CONDITIONS

X1.1 Any exposure conditions may be used, as long as the exact conditions are detailed in the report. Following are some representative exposure conditions. These are not preferred necessarily and no recommendation is implied. These conditions are provided for reference only (see Table X1.1).

X1.2 For conversion of test cycles see Table X1.2.

TABLE X1.1 Common Exposure Conditions

NOTE 1—Historical convention has established Cycle 1a as a very commonly used exposure cycle. Other cycles may give a better simulation of the effects of outdoor exposure. Cycle 2 has been used for exterior textiles. Cycle 3, 4, and 5 have been used for exterior coatings and stains. Cycle 6 has been used for lightfastness of indoor materials. The operational fluctuation values given for the set point temperatures are those that have been historically used for these exposures and may be above the maximum operational fluctuation given in Practice G 151.

NOTE 2—More complex cycles may be programmed in conjunction with dark periods that allow high relative humidities and the formation of condensate at elevated chamber temperatures. Condensation may be produced on the face of the specimens by spraying the rear side of them to cool them below the dewpoint.

NOTE 3—For special tests, high operating temperatures may be desirable, but this will increase the tendency for thermal degradation to adversely influence the test results.

NOTE 4—Surface temperature of specimens is an essential test quantity. Generally, degradation processes accelerate with increasing temperature. The specimen temperature recommended for the accelerated test depends on the material to be tested and on the aging criterion under consideration.

NOTE 5—The relative humidity of the air as measured in the test chamber is not necessarily equivalent to the relative humidity of the air very close to the specimen surface. This is because test specimens having varying colors and thicknesses may be expected to vary in temperature.

Cycle	Filter	Exposure Cycle
1	Daylight	102 min light at 63 (±3)°C black panel temperature 18 min light and water spray air temperature not controlled)
1a	Extended UV	102 min light at 63 (±3)°C black panel temperature 18 min light and water spray air temperature not controlled)
2	Daylight	90 min light, 70 (±5) % RH, at 77 (±3)°C black panel temperature 30 min light and water spray (air temperature not controlled)
3	Daylight	102 min light at 63 (±3)°C uninsulated black panel temperature 18 min light & water spray, air temperature not controlled repeated nine times for a total of 18h, followed by 6 h dark at 95 % (±4.0) RH, at 24 (±2.5)°C
3a	Extended UV	102 min light at 63 (±3)°C uninsulated black panel temperature 18 min light & water spray, air temperature not controlled repeated nine times for a total of 18h, followed by 6 h dark at 95 (±4.0) % RH, at 24 (±2.5)°C
4	Daylight	4 h light at 63 (±3)°C black panel temperature 4 h light & water spray (air temperature not controlled)
5	Daylight	12 h light as 63 (±3)°C black panel temperature 12 h light and water spray (air temperature not controlled)
6	Window Glass	100 % light at 63 (±3)°C black panel temperature

TABLE X1.2 Conversion of Test Cycles from G23 to G152

G23 Test Cycle Description for E or EH Devices	Corresponding Test Cycle in G152
G 23, Method 1 — Continuous light with intermittent water spray	G152, Table X1.1 Cycle 1a is the same as the one specific condition described in G23, Method 1
Many conditions could be used, but the following is the only specific condition described	
102 min light only (uninsulated black panel temperature at 63 ± 2.5°C) 18 min light + water spray humidity set point not defined	
G23– Method 2 — alternate exposure to light and dark and intermittent exposure to water spray	Cycles 2, 3, 4, and 5 in G152, Table X1.1 provide alternate exposure to light and dark intermittent exposure to water spray. Cycle 3a has an 18h period with the same light and water spray conditions as G23
Requires use of a humidity controlled device with a specimen neck diameter at 959 nm (Type EH). No specific light/dark/water cycle described	
Light period conditions same as for Method 1	Method 1 followed by a 6h dark period at very high relative humidity
Humidity set point not defined	
Length of dark period not defined	
G23– Method 3 — continuous exposure to light with no water spray	G152, Table X1.1, cycle 6 uses the same conditions but requires use of window glass filters
Uninsulated black panel at 63 ± 2.5°C, RH at 30 ± 5% for devices with humidity control	

X2. COMPARISON OF BENCHMARK SOLAR UV SPECTRUM WITH THE CIE 85 TABLE 4 SOLAR UV SPECTRUM

X2.1 This standard uses a benchmark solar spectrum based on atmospheric conditions that provide for a very high level of solar ultraviolet radiation. This benchmark solar spectrum is published in ASTM G 177, Standard Tables for Reference Solar Ultraviolet Spectral Distributions: Hemispherical on 37 degree Tilted Surface. The solar spectrum is calculated using the SMARTS2 solar radiation model.[8,9,10] ASTM Adjunct ADJG0173, SMARTS2 Solar Radiation Model for Spectral Radiation provides the program and documentation for calculating solar spectral irradiance.

X2.2 Previous versions of this standard used CIE 85 Table 4 [11] as the benchmark solar spectra. Table X2.1 compares the basic atmospheric conditions used for the benchmark solar spectrum and the CIE 85 Table 4 solar spectrum.

X2.3 Table X2.2 compares irradiance (calculated using rectangular integration) and relative irradiance for the benchmark solar spectra and the CIE 85 Table 4 solar spectrum, in the bandpasses used in this standard.

[8] Gueymard, C., "Parameterized Transmittance Model for Direct Beam and Circumsolar Spectral Irradiance," *Solar Energy*, Vol 71, No. 5, 2001, pp. 325-346.

[9] Gueymard, C. A., Myers, D., and Emery, K., "Proposed Reference Irradiance Spectra for Solar Energy Systems Testing," *Solar Energy*, Vol 73, No 6, 2002, pp. 443-467.

[10] Myers, D. R., Emery, K., and Gueymard, C., "Revising and Validating Spectral Irradiance Reference Standards for Photovoltaic Performance Evaluation," Proceedings of Solar 2002 – Sunrise on the Reliable Energy Economy, Reno, NV, June 15-20, 2002.

[11] CIE-Publication Number 85: Recommendations for the Integrated Irradiance and the Spectral Distribution of Simulated Solar Radiation for Testing Purposes, 1st Edition, 1989 (Available from American National Standards Institute, 11 W. 42nd St., 13th Floor, New York, NY 10036).

TABLE X2.1 Comparison of Basic Atmospheric Conditions Used for the Benchmark Solar Spectrum and CIE 85 Table 4 Solar Spectrum

Atmospheric Condition	Benchmark Solar Spectrum	CIE 85 Table 4 Solar Spectrum
Ozone (atm-cm)	0.30	0.34
Precipitable water vapor (cm)	0.57	1.42
Altitude (m)	2000	0
Tilt angle	37° facing Equator	0° (horizontal)
Air mass	1.05	1.00
Albedo (ground reflectance)	Light Soil wavelength dependent	Constant at 0.2
Aerosol extinction	Shettle & Fenn Rural (humidity dependent)	Equivalent to Linke Turbidity factor of about 2.8
Aerosol optical thickness at 500 nm	0.05	0.10

TABLE X2.2 Irradiance and Relative Irradiance Comparison for Benchmark Solar Spectrum and CIE 85 Table 4 Solar Spectrum

Bandpass	Benchmark Solar Spectrum	CIE 85 Table 4 Solar Spectrum
	Irradiance (W/m²) in stated bandpass	
λ < 290	0.000	0.000
290 ≤ λ ≤ 320	3.748	4.060
320 < λ ≤ 360	25.661	28.450
360 < λ ≤ 400	34.762	42.050
290 ≤ λ ≤ 400	64.171	74.560
290 ≤ λ ≤ 800	652.300	678.780
	Percent of 290 to 400 nm irradiance	
λ < 290	0.0 %	0.0 %
290 < λ ≤ 320	5.8 %	5.4 %
320 < λ ≤ 360	40.0 %	38.2 %
360 < λ ≤ 400	54.2 %	56.4 %
	Percent of 290 to 800 nm irradiance	
290 ≤ λ ≤ 400	9.8 %	11.0 %

Designation: G 154 – 06

Standard Practice for Operating Fluorescent Light Apparatus for UV Exposure of Nonmetallic Materials[1]

This standard is issued under the fixed designation G 154; the number immediately following the designation indicates the year of original adoption or, in the case of revision, the year of last revision. A number in parentheses indicates the year of last reapproval. A superscript epsilon (ε) indicates an editorial change since the last revision or reapproval.

Note—A footnote was added to Table X2.1, Table X2.3 was added, a new Note X2.8 was added, and the year date was changed on June 5, 2006.

1. Scope

1.1 This practice covers the basic principles and operating procedures for using fluorescent UV light, and water apparatus intended to reproduce the weathering effects that occur when materials are exposed to sunlight (either direct or through window glass) and moisture as rain or dew in actual usage. This practice is limited to the procedures for obtaining, measuring, and controlling conditions of exposure. A number of exposure procedures are listed in an appendix; however, this practice does not specify the exposure conditions best suited for the material to be tested.

Note 1—Practice G 151 describes performance criteria for all exposure devices that use laboratory light sources. This practice replaces Practice G 53, which describes very specific designs for devices used for fluorescent UV exposures. The apparatus described in Practice G 53 is covered by this practice.

1.2 Test specimens are exposed to fluorescent UV light under controlled environmental conditions. Different types of fluorescent UV light sources are described.

1.3 Specimen preparation and evaluation of the results are covered in ASTM methods or specifications for specific materials. General guidance is given in Practice G 151 and ISO 4892-1. More specific information about methods for determining the change in properties after exposure and reporting these results is described in ISO 4582.

1.4 The values stated in SI units are to be regarded as the standard.

1.5 *This standard does not purport to address all of the safety concerns, if any, associated with its use. It is the responsibility of the user of this standard to establish appropriate safety and health practices and determine the applicability of regulatory limitations prior to use.*

1.6 This standard is technically similar to ISO 4892-3 and ISO DIS 11507.

2. Referenced Documents

2.1 *ASTM Standards:* [2]

D 3980 Practice for Interlaboratory Testing of Paint and Related Materials

E 691 Practice for Conducting an Interlaboratory Study to Determine the Precision of a Test Method

G 53 Practice for Operating Light- and Water-Exposure Apparatus (Fluorescent UV-Condensation Type) for Exposure of Nonmetallic Materials

G 113 Terminology Relating to Natural and Artificial Weathering Tests for Nonmetallic Materials

G 151 Practice for Exposing Nonmetallic Materials in Accelerated Test Devices That Use Laboratory Light Sources

2.2 *CIE Standard:*

CIE-Publ. No. 85: Recommendations for the Integrated Irradiance and the Spectral Distribution of Simulated Solar Radiation for Testing Purposes[3]

2.3 *ISO Standards:*

ISO 4582, Plastics—Determination of the Changes of Colour and Variations in Properties After Exposure to Daylight Under Glass, Natural Weathering or Artificial Light[4]

ISO 4892-1, Plastics—Methods of Exposure to Laboratory Light Sources, Part 1, Guidance[4]

ISO 4892-3, Plastics—Methods of Exposure to Laboratory Light Sources, Part 3, Fluorescent UV lamps[4]

ISO DIS 11507, Paint and Varnishes—Exposure of Coatings to Artificial Weathering in Apparatus—Exposure to Fluorescent Ultraviolet and Condensation Apparatus[4]

3. Terminology

3.1 *Definitions*—The definitions given in Terminology G 113 are applicable to this practice.

[1] This practice is under the jurisdiction of ASTM Committee G03 on Weathering and Durability and is the direct responsibility of Subcommittee G03.03 on Simulated and Controlled Exposure Tests.

Current edition approved June 5, 2006. Published June 2006. Originally approved in 1997. Last previous edition approved in 2005 as G 154 – 05.

[2] For referenced ASTM standards, visit the ASTM website, www.astm.org, or contact ASTM Customer Service at service@astm.org. For *Annual Book of ASTM Standards* volume information, refer to the standard's Document Summary page on the ASTM website.

[3] Available from Secretary, U.S. National Committee, CIE, National Institute of Standards and Technology (NIST), Gaithersburg, MD 20899.

[4] Available from American National Standards Institute (ANSI), 25 W. 43rd St., 4th Floor, New York, NY 10036.

3.2 *Definitions of Terms Specific to This Standard*—As used in this practice, the term *sunlight* is identical to the terms *daylight* and *solar irradiance, global* as they are defined in Terminology G 113.

4. Summary of Practice

4.1 Specimens are exposed to repetitive cycles of light and moisture under controlled environmental conditions.

4.1.1 Moisture is usually produced by condensation of water vapor onto the test specimen or by spraying the specimens with demineralized/deionized water.

4.2 The exposure condition may be varied by selection of:

4.2.1 The fluorescent lamp,

4.2.2 The lamp's irradiance level,

4.2.3 The type of moisture exposure,

4.2.4 The timing of the light and moisture exposure,

4.2.5 The temperature of light exposure, and

4.2.6 The temperature of moisture exposure, and

4.2.7 The timing of a light/dark cycle.

4.3 Comparison of results obtained from specimens exposed in same model of apparatus should not be made unless reproducibility has been established among devices for the material to be tested.

4.4 Comparison of results obtained from specimens exposed in different models of apparatus should not be made unless correlation has been established among devices for the material to be tested.

5. Significance and Use

5.1 The use of this apparatus is intended to induce property changes associated with the end use conditions, including the effects of the UV portion of sunlight, moisture, and heat. These exposures may include a means to introduce moisture to the test specimen. Exposures are not intended to simulate the deterioration caused by localized weather phenomena, such as atmospheric pollution, biological attack, and saltwater exposure. Alternatively, the exposure may simulate the effects of sunlight through window glass. Typically, these exposures would include moisture in the form of condensing humidity.

NOTE 2—**Caution:** Refer to Practice G 151 for full cautionary guidance applicable to all laboratory weathering devices.

5.2 Variation in results may be expected when operating conditions are varied within the accepted limits of this practice. Therefore, no reference shall be made to results from the use of this practice unless accompanied by a report detailing the specific operating conditions in conformance with the Section 10.

5.2.1 It is recommended that a similar material of known performance (a control) be exposed simultaneously with the test specimen to provide a standard for comparative purposes. It is recommended that at least three replicates of each material evaluated be exposed in each test to allow for statistical evaluation of results.

6. Apparatus

6.1 *Laboratory Light Source*—The light source shall be fluorescent UV lamps. A variety of fluorescent UV lamps can be used for this procedure. Differences in lamp intensity or spectrum may cause significant differences in test results. A detailed description of the type(s) of lamp(s) used should be stated in detail in the test report. The particular testing application determines which lamp should be used. See Appendix X1 for lamp application guidelines.

NOTE 3—Do not mix different types of lamps. Mixing different types of lamps in a fluorescent UV light apparatus may produce major inconsistencies in the light falling on the samples, unless the apparatus has been specifically designed to ensure a uniform spectral distribution.

NOTE 4—Many fluorescent lamps age significantly with extended use. Follow the apparatus manufacturer's instructions on the procedure necessary to maintain desired irradiance **(1,2)**.

6.1.1 Actual irradiance levels at the test specimen surface may vary due to the type or manufacturer of the lamp used, or both, the age of the lamps, the distance to the lamp array, and the air temperature within the chamber and the ambient laboratory temperature. Consequently, the use of a radiometer to monitor and control the radiant energy is recommended.

6.1.2 Several factors can affect the spectral power distribution of fluorescent UV lamps:

6.1.2.1 Aging of the glass used in some types of lamps can result in changes in transmission. Aging of glass can result in a significant reduction in the short wavelength UV emission of some lamp types,

6.1.2.2 Accumulation of dirt or other residue on lamps can affect irradiance,

6.1.2.3 Thickness of glass used for lamp tube can have large effects on the amount of short wavelength UV radiation transmitted, and

6.1.2.4 Uniformity and durability of phosphor coating.

6.1.3 *Spectral Irradiance*:

NOTE 5—Fluorescent UVA lamps are available with a choice of spectral power distributions that vary significantly. The more common may be identified as UVA-340 and UVA-351. These numbers represent the characteristic nominal wavelength (in nm) of peak emission for each of these lamp types. The actual peak emissions are at 343 and 350 nm, respectively.

6.1.3.1 *Spectral Irradiance of UVA-340 Lamps for Daylight UV*—The spectral power distribution of UVA-340 fluorescent lamps shall comply with the requirements specified in Table 1.

NOTE 6—The main application for UVA-340 lamps is for simulation of the short and middle UV wavelength region of daylight.

6.1.3.2 *Spectral Irradiance of UVA-351 Lamps for Daylight UV Behind Window Glass*—The spectral power distribution of UVA-351 lamp for Daylight UV behind Window Glass shall comply with the requirements specified in Table 2.

NOTE 7—The main application for UVA-351 lamps is for simulation of the short and middle UV wavelength region of daylight which has been filtered through window glass **(3)**.

6.1.3.3 *Spectral Irradiance of UVB-313 Lamps*—The spectral power distribution of UVB-313 fluorescent lamps shall comply with the requirements specified in Table 3.

NOTE 8—Fluorescent UVB lamps have the spectral distribution of radiation peaking near the 313-nm mercury line. They emit significant amounts of radiation below 300 nm, the nominal cut on wavelength of global solar radiation, that may result in aging processes not occurring outdoors. Use of this lamp is not recommended for sunlight simulation. See Table 3.

TABLE 1 Relative Ultraviolet Spectral Power Distribution Specification for Fluorescent UVA-340 Lamps for Daylight UV[A,B]

Spectral Bandpass Wavelength λ in nm	Minimum Percent[C]	Benchmark Solar Radiation Percent[D,E,F]	Maximum Percent[C]
$\lambda < 290$			0.01
$290 \leq \lambda \leq 320$	5.9	5.8	9.3
$320 < \lambda \leq 360$	60.9	40.0	65.5
$360 < \lambda \leq 400$	26.5	54.2	32.8

[A] Data in Table 1 are the irradiance in the given bandpass expressed as a percentage of the total irradiance from 290 to 400 nm. The manufacturer is responsible for determining conformance to Table 1. Annex A1 states how to determine relative spectral irradiance.

[B] The data in Table 1 are based on the rectangular integration of 65 spectral power distributions for fluorescent UV devices operating with UVA 340 lamps of various lots and ages. The spectral power distribution data is for lamps within the aging recommendations of the device manufacturer. The minimum and maximum data are at least the three sigma limits from the mean for all measurements.

[C] The minimum and maximum columns will not necessarily sum to 100 % because they represent the minimum and maximum for the data used. For any individual spectral power distribution, the calculated percentage for the bandpasses in Table 1 will sum to 100 %. For any individual fluorescent UVA-340 lamp, the calculated percentage in each bandpass must fall within the minimum and maximum limits of Table 1. Test results can be expected to differ between exposures using devices with fluorescent UVA-340 lamps in which the spectral power distributions differ by as much as that allowed by the tolerances. Contact the manufacturer of the fluorescent UV devices for specific spectral power distribution data for the fluorescent UVA-340 lamp used.

[D] The benchmark solar radiation data is defined in ASTM G 177 and is for atmospheric conditions and altitude chosen to maximize the fraction of short wavelength solar UV. While this data is provided for comparison purposes only, it is desirable for the laboratory accelerated light source to provide a spectrum that is a close match to the benchmark solar spectrum.

[E] Previous versions of this standard used solar radiation data from Table 4 of CIE Publication Number 85. See Appendix X3 for more information comparing the solar radiation data used in this standard with that for CIE 85 Table 4.

[F] For the benchmark daylight spectrum, the UV irradiance (290 to 400 nm) is 9.8 % and the visible irradiance (400 to 800 nm) is 90.2 % expressed as a percentage of the total irradiance from 290 to 800 nm. Because the primary emission of fluorescent UV lamps is concentrated in the 300 to 400 nm bandpass, there are limited data available for visible light emissions of fluorescent UV lamps.

6.2 *Test Chamber*—The design of the test chamber may vary, but it should be constructed from corrosion resistant material and, in addition to the radiant source, may provide for means of controlling temperature and relative humidity. When required, provision shall be made for the spraying of water on the test specimen for the formation of condensate on the exposed face of the specimen or for the immersion of the test specimen in water.

6.2.1 The radiant source(s) shall be located with respect to the specimens such that the uniformity of irradiance at the specimen face complies with the requirements in Practice G 151.

6.2.2 Lamp replacement, lamp rotation, and specimen repositioning may be required to obtain uniform exposure of all specimens to UV radiation and temperature. Follow manufacturer's recommendation for lamp replacement and rotation.

6.3 *Instrument Calibration*—To ensure standardization and accuracy, the instruments associated with the exposure apparatus (for example, timers, thermometers, wet bulb sensors, dry bulb sensors, humidity sensors, UV sensors, and radiometers) require periodic calibration to ensure repeatability of test results. Whenever possible, calibration should be traceable to national or international standards. Calibration schedule and procedure should be in accordance with manufacturer's instructions.

6.4 *Radiometer*—The use of a radiometer to monitor and control the amount of radiant energy received at the sample is

TABLE 2 Relative Spectral Power Distribution Specification for Fluorescent UVA-351 Lamps for Daylight UV Behind Window Glass[A,B]

Spectral Bandpass Wavelength λ in nm	Minimum Percent[C]	Window Glass Filtered Daylight Percent[D,E,F]	Maximum Percent[C]
$\lambda < 300$		0.0	0.2
$300 \leq \lambda \leq 320$	1.1	≤ 0.5	3.3
$320 < \lambda \leq 360$	60.5	34.2	66.8
$360 < \lambda \leq 400$	30.0	65.3	38.0

[A] Data in Table 2 are the irradiance in the given bandpass expressed as a percentage of the total irradiance from 300 to 400 nm. The manufacturer is responsible for determining conformance to Table 1. Annex A1 states how to determine relative spectral irradiance.

[B] The data in Table 2 are based on the rectangular integration of 21 spectral power distributions for fluorescent UV devices operating with UVA 351 lamps of various lots and ages. The spectral power distribution data is for lamps within the aging recommendations of the device manufacturer. The minimum and maximum data are at least the three sigma limits from the mean for all measurements.

[C] The minimum and maximum columns will not necessarily sum to 100 % because they represent the minimum and maximum for the data used. For any individual spectral power distribution, the calculated percentage for the bandpasses in Table 2 will sum to 100 %. For any individual fluorescent UV device operating with UVA 351 lamps, the calculated percentage in each bandpass must fall within the minimum and maximum limits of Table 2. Test results can be expected to differ between exposures using fluorescent UV devices in which the spectral power distributions differ by as much as that allowed by the tolerances. Contact the manufacturer of the fluorescent UV devices for specific spectral power distribution data for the lamps used.

[D] The window glass filtered solar radiation data is for a solar spectrum with atmospheric conditions and altitude chosen to maximize the fraction of short wavelength solar UV (defined in ASTM G 177) that has been filtered by window glass. The glass transmission is the average for a series of single strength window glasses tested as part of a research study for ASTM Subcommittee G3.02.[9] While this data is provided for comparison purposes only, it is desirable for the laboratory accelerated light source to provide a spectrum that is a close match to this benchmark window glass filtered solar spectrum.

[E] Previous versions of this standard used window glass filtered solar radiation data based on Table 4 of CIE Publication Number 85. See Appendix X3 for more information comparing the solar radiation data used in the standard with that for CIE 85 Table 4.

[F] For the benchmark window glass filtered solar spectrum, the UV irradiance (300 to 400 nm) is 8.2 % and the visible irradiance (400 to 800 nm) is 91.8 % expressed as a percentage of the total irradiance from 300 to 800 nm. Because the primary emission of fluorescent UV lamps is concentrated in the 300 to 400 nm bandpass, there are limited data available for visible light emissions of fluorescent UV lamps.

recommended. If a radiometer is used, it shall comply with the requirements in Practice G 151.

6.5 *Thermometer*—Either insulated or un-insulated black or white panel thermometers may be used. The un-insulated thermometers may be made of either steel or aluminum. Thermometers shall conform to the descriptions found in Practice G 151.

6.5.1 The thermometer shall be mounted on the specimen rack so that its surface is in the same relative position and subjected to the same influences as the test specimens.

6.5.2 Some specifications may require chamber air temperature control. Positioning and calibration of chamber air temperature sensors shall be in accordance with the descriptions found in Practice G 151.

NOTE 9—Typically, these devices control by black panel temperature only.

6.6 *Moisture*—The test specimens may be exposed to moisture in the form of water spray, condensation, or high humidity.

6.6.1 *Water Spray*—The test chamber may be equipped with a means to introduce intermittent water spray onto the test specimens under specified conditions. The spray shall be

TABLE 3 Relative Spectral Power Distribution Specification for Fluorescent UVB 313 lamps[A,B]

Spectral Bandpass Wavelength λ in nm	Minimum Percent[C]	Benchmark Solar Radiation Percent[D,E,F]	Maximum Percent[C]
$\lambda < 290$	1.3		5.4
$290 \le \lambda \le 320$	47.8	5.8	65.9
$320 < \lambda \le 360$	26.9	40.0	43.9
$360 < \lambda \le 400$	1.7	54.2	7.2

[A] Data in Table 3 are the irradiance in the given bandpass expressed as a percentage of the total irradiance from 250 to 400 nm. The manufacturer is responsible for determining conformance to Table 3. Annex A1 states how to determine relative spectral irradiance.

[B] The data in Table 3 are based on the rectangular integration of 44 spectral power distributions for fluorescent UV devices operating with UVB 313 lamps of various lots and ages. The spectral power distribution data is for lamps within the aging recommendations of the device manufacturer. The minimum and maximum data are at least the three sigma limits from the mean for all measurements.

[C] The minimum and maximum columns will not necessarily sum to 100 % because they represent the minimum and maximum for the data used. For any individual spectral power distribution, the calculated percentage for the bandpasses in Table 3 will sum to 100 %. For any individual UVB 313 lamp, the calculated percentage in each bandpass must fall within the minimum and maximum limits of Table 3. Test results can be expected to differ between exposures conducted in fluorescent UV devices using UVB 313 lamps in which the spectral power distributions differ by as much as that allowed by the tolerances. Contact the manufacturer of the fluorescent UV device for specific spectral power distribution data for the device operated with the UVB 313 lamp used.

[D] The benchmark solar radiation data is defined in ASTM G 177 and is for atmospheric conditions and altitude chosen to maximize the fraction of short wavelengthsolar UV. This data is provided for comparison purposes only.

[E] Previous versions of this standard used solar radiation data from Table 4 of CIE Publication Number 85. See Appendix X3 for more information comparing the solar radiation data used in this standard with that for CIE 85 Table 4.

[F] For the benchmark solar spectrum, the UV irradiance (290 to 400 nm) is 9.8 % and the visible irradiance (400 to 800 nm) is 90.2 % expressed as a percentage of the total irradiance from 290 to 800 nm. Because the primary emission of fluorescent UV lamps is concentrated in the 300 to 400 nm bandpass, there are limited data available for visible light emissions of fluorescent UV lamps.

uniformly distributed over the samples. The spray system shall be made from corrosion resistant materials that do not contaminate the water used.

6.6.1.1 *Spray Water Quality*—Spray water shall have a conductivity below 5 μS/cm, contain less than 1-ppm solids, and leave no observable stains or deposits on the specimens. Very low levels of silica in spray water can cause significant deposits on the surface of test specimens. Care should be taken to keep silica levels below 0.1 ppm. In addition to distillation, a combination of deionization and reverse osmosis can effectively produce water of the required quality. The pH of the water used should be reported. See Practice G 151 for detailed water quality instructions.

6.6.2 *Condensation*—The test chamber may be equipped with a means to cause condensation to form on the exposed face of the test specimen. Typically, water vapor shall be generated by heating water and filling the chamber with hot vapor, which then is made to condense on the test specimens.

6.6.3 *Relative Humidity*—The test chamber may be equipped with a means to measure and control the relative humidity. Such instruments shall be shielded from the lamp radiation.

6.7 *Specimen Holders*—Holders for test specimens shall be made from corrosion resistant materials that will not affect the test results. Corrosion resistant alloys of aluminium or stainless steel have been found acceptable. Brass, steel, or copper shall not be used in the vicinity of the test specimens.

6.8 *Apparatus to Assess Changes in Properties*—Use the apparatus required by the ASTM or other standard that describes determination of the property or properties being monitored.

7. Test Specimen

7.1 Refer to Practice G 151.

8. Test Conditions

8.1 Any exposure conditions may be used as long as the exact conditions are detailed in the report. Appendix X2 shows some representative exposure conditions. These are not necessarily preferred and no recommendation is implied. These conditions are provided for reference only.

9. Procedure

9.1 Identify each test specimen by suitable indelible marking, but not on areas used in testing.

9.2 Determine which property of the test specimens will be evaluated. Prior to exposing the specimens, quantify the appropriate properties in accordance with recognized ASTM or international standards. If required (for example, destructive testing), use unexposed file specimens to quantify the property. See ISO 4582 for detailed guidance.

9.3 *Mounting of Test Specimens*—Attach the specimens to the specimen holders in the equipment in such a manner that the specimens are not subject to any applied stress. To assure uniform exposure conditions, fill all of the spaces, using blank panels of corrosion resistant material if necessary.

NOTE 10—Evaluation of color and appearance changes of exposed materials shall be made based on comparisons to unexposed specimens of the same material which have been stored in the dark. Masking or shielding the face of test specimens with an opaque cover for the purpose of showing the effects of exposure on one panel is not recommended. Misleading results may be obtained by this method, since the masked portion of the specimen is still exposed to temperature and humidity that in many cases will affect results.

9.4 *Exposure to Test Conditions*—Program the selected test conditions to operate continuously throughout the required number of repetitive cycles. Maintain these conditions throughout the exposure. Interruptions to service the apparatus and to inspect specimens shall be minimized.

9.5 *Specimen Repositioning*—Periodic repositioning of the specimens during exposure is not necessary if the irradiance at the positions farthest from the center of the specimen area is at least 90 % of that measured at the center of the exposure area. Irradiance uniformity shall be determined in accordance with Practice G 151.

9.5.1 If irradiance at positions farther from the center of the exposure area is between 70 and 90 % of that measured at the center, one of the following three techniques shall be used for specimen placement.

9.5.1.1 Periodically reposition specimens during the exposure period to ensure that each receives an equal amount of radiant exposure. The repositioning schedule shall be agreed upon by all interested parties.

9.5.1.2 Place specimens only in the exposure area where the irradiance is at least 90 % of the maximum irradiance.

9.5.1.3 To compensate for test variability randomly position replicate specimens within the exposure area which meets the irradiance uniformity requirements as defined in 9.5.1.

9.6 *Inspection*—If it is necessary to remove a test specimen for periodic inspection, take care not to handle or disturb the test surface. After inspection, the test specimen shall be returned to the test chamber with its test surface in the same orientation as previously tested.

9.7 *Apparatus Maintenance*—The test apparatus requires periodic maintenance to maintain uniform exposure conditions. Perform required maintenance and calibration in accordance with manufacturer's instructions.

9.8 Expose the test specimens for the specified period of exposure. See Practice G 151 for further guidance.

9.9 At the end of the exposure, quantify the appropriate properties in accordance with recognized ASTM or international standards and report the results in conformance with Practice G 151.

NOTE 11—Periods of exposure and evaluation of test results are addressed in Practice G 151.

10. Report

10.1 The test report shall conform to Practice G 151.

11. Precision and Bias

11.1 *Precision*:

11.1.1 The repeatability and reproducibility of results obtained in exposures conducted according to this practice will vary with the materials being tested, the material property being measured, and the specific test conditions and cycles that are used. In round-robin studies conducted by Subcommittee G03.03, the 60° gloss values of replicate PVC tape specimens exposed in different laboratories using identical test devices and exposure cycles showed significant variability **(3)**. The variability shown in these round-robin studies restricts the use of "absolute specifications" such as requiring a specific property level after a specific exposure period **(4,5)**.

11.1.2 If a standard or specification for general use requires a definite property level after a specific time or radiant exposure in an exposure test conducted according to this practice, the specified property level shall be based on results obtained in a round-robin that takes into consideration the variability due to the exposure and the test method used to measure the property of interest. The round-robin shall be conducted according to Practice E 691 or Practice D 3980 and shall include a statistically representative sample of all laboratories or organizations that would normally conduct the exposure and property measurement.

11.1.3 If a standard or specification for use between two or three parties requires a definite property level after a specific time or radiant exposure in an exposure test conducted according to this practice, the specified property level shall be based on statistical analysis of results from at least two separate, independent exposures in each laboratory. The design of the experiment used to determine the specification shall take into consideration the variability due to the exposure and the test method used to measure the property of interest.

11.1.4 The round-robin studies cited in 11.1.1 demonstrated that the gloss values for a series of materials could be ranked with a high level of reproducibility between laboratories. When reproducibility in results from an exposure test conducted according to this practice have not been established through round-robin testing, performance requirements for materials shall be specified in terms of comparison (ranked) to a control material. The control specimens shall be exposed simultaneously with the test specimen(s) in the same device. The specific control material used shall be agreed upon by the concerned parties. Expose replicates of the test specimen and the control specimen so that statistically significant performance differences can be determined.

11.2 *Bias*—Bias can not be determined because no acceptable standard weathering reference materials are available.

12. Keywords

12.1 accelerated; accelerated weathering; durability; exposure; fluorescent UV lamps; laboratory weathering; light; lightfastness; non-metallic materials; temperature; ultraviolet; weathering

ANNEX

A1. DETERMINING CONFORMANCE TO RELATIVE SPECTRAL POWER DISTRIBUTION TABLES

(Mandatory Information for Equipment Manufacturers)

A1.1 Conformance to the relative spectral power distribution tables is a design parameter for fluorescent UV device with the different lamps that can be used. Manufacturers of equipment claiming conformance to this standard shall determine conformance to the spectral power distribution tables for all fluorescent lamps provided, and provide information on maintenance procedures to minimize any spectral changes that may occur during normal use.

A1.2 The relative spectral power distribution data for this standard were developed using the rectangular integration technique. Eq A1.1 is used to determine the relative spectral irradiance using rectangular integration. Other integration techniques can be used to evaluate spectral power distribution data, but may give different results. When comparing relative spectral power distribution data to the spectral power distribution requirements of this standard, use the rectangular integration technique.

A1.3 To determine whether a specific fluorescent UV lamp for a fluorescent UV device meets the requirements of Table 1, Table 2, or Table 3, measure the spectral power distribution from 250 nm to 400 nm. Typically, this is done at 2 nm increments. If the manufacturer's spectral measurement equipment cannot measure wavelengths as low as 250 nm, the lowest measurement wavelength must be reported. The lowest wavelength measured shall be no greater than 270 nm. For determining conformance to the relative spectral irradiance requirements for a fluorescent UVB-313 lamp, measurement from 250 nm to 400 nm is required. The total irradiance in each wavelength bandpass is then summed and divided by the specified total UV irradiance according to Eq A1.1. Use of this equation requires that each spectral interval must be the same (for example, 2 nm) throughout the spectral region used.

$$I_R = \frac{\sum_{\lambda_i=A}^{\lambda_i=B} E_{\lambda_i}}{\sum_{\lambda_i=C}^{\lambda_i=400} E_{\lambda_i}} \times 100 \quad (A1.1)$$

where:

I_R = relative irradiance in percent,
E = irradiance at wavelength λ_i (irradiance steps must be equal for all bandpasses),
A = lower wavelength of wavelength bandpass,
B = upper wavelength of wavelength bandpass,
C = lower wavelength of total UV bandpass used for calculating relative spectral irradiance (290 nm for UVA 340 lamps, 300 nm for UVA 351 lamps, or 250 nm for UVB 313 lamps), and
λ_i = wavelength at which irradiance was measured.

APPENDIXES

(Nonmandatory Information)

X1. APPLICATION GUIDELINES FOR TYPICAL FLUORESCENT UV LAMPS

X1.1 *General:*

X1.1.1 A variety of fluorescent UV lamps may be used in this practice. The lamps shown in this section are representative of their type. Other lamps, or combinations of lamps, may be used. The particular application determines which lamp should be used. The lamps discussed in this Appendix differ in the total amount of UV energy emitted and their wavelength spectrum. Differences in lamp energy or spectrum may cause significant differences in test results. A detailed description of the type(s) of lamp(s) used shall be stated in detail in the test report.

X1.1.2 All spectral power distributions (SPDs) shown in this section are representative only and are not meant to be used to calculate or estimate total radiant exposure for tests in fluorescent UV devices. Actual irradiance levels at the test specimen surface will vary due to the type and/or manufacturer of the lamp used, the age of the lamps, the distance to the lamp array, and the air temperature within the chamber.

NOTE X1.1—All SPDs in this appendix were measured using a spectroradiometer with a double grating monochromator (1-nm band pass) with a quartz cosine receptor. The fluorescent UV SPDs were measured at the sample plane in the center of the allowed sample area. SPDs for sunlight were measured in Phoenix, AZ at solar noon at the summer solstice with a clear sky, with the spectroradiometer on an equatorial follow-the-sum mount.

X1.2 *Simulations of Direct Solar UV Radiation Exposures:*

X1.2.1 *UVA-340 Lamps*—For simulations of direct solar UV radiation the UVA-340 lamp is recommended. Because UVA-340 lamps typically have little or no UV output below 300 nm (that is considered the "cut-on" wavelength for terrestrial sunlight), they usually do not degrade materials as rapidly as UVB lamps, but they may allow enhanced correlation with actual outdoor weathering. Tests using UVA-340 lamps have been found useful for comparing different nonmetallic materials such as polymers, textiles, and UV stabilizers. Fig. X1.1 illustrates the SPD of the UVA-340 lamp compared to noon, summer sunlight.

X1.2.2 *UVB-313 Lamps*—The UVB region (280 to 315 nm) includes the shortest wavelengths found in sunlight at the earth's surface and is responsible for considerable polymer damage. There are two commonly available types of UVB-313 lamps that meet the requirements of this document. These are known commercially as the UVB-313 and the FS-40. These lamps emit different amounts of total energy, but both peak at 313 nm and produce the same UV wavelengths in the same relative proportions. In tests using the same cycles and temperatures, shorter times to failure are typically observed when the lamp with higher UV irradiance is used. Furthermore, tests using the same cycles and temperatures with these two lamps may exhibit differences in ranking of materials due to difference in the proportion of UV to moisture and temperature.

NOTE X1.2—The Fig. X1.2 illustrates the difference between the lamps.

X1.2.2.1 All UVB-313 lamps emit UV below the normal sunlight cut-on. This short wavelength UV can produce rapid polymer degradation and often causes degradation by mechanisms that do not occur when materials are exposed to sunlight. This may lead to anomalous results. Fig. X1.2 shows the spectral power distribution (SPD) of typical UVB-313 lamps compared to the SPD of noon, summer sunlight.

X1.3 *Simulations of Exposures to Solar UV Radiation Through Window Glass*:

X1.3.1 *Filtering Effect of Glass*—Glass of any type acts as a filter on the sunlight spectrum (see Fig. X1.3). Ordinary glass is essentially transparent to light above about 370 nm. However, the filtering effect becomes more pronounced with decreasing wavelength. The shorter, more damaging UVB wavelengths are the most greatly affected. Window glass filters out most of the wavelengths below about 310 nm. For purposes of illustration, only one type of window glass is used in the accompanying graphs. Note that glass transmission characteristics will vary due to manufacturer, production lot, thickness, or other factors.

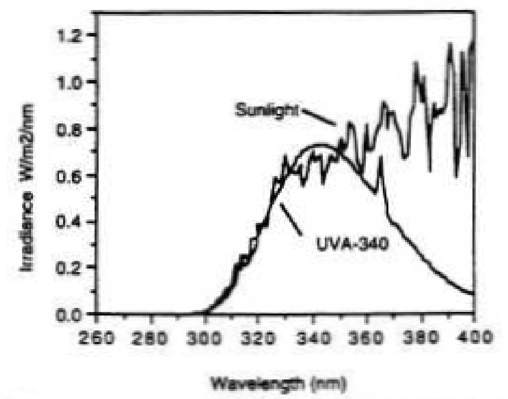

FIG. X1.1 Spectral Power Distributions of UVA-340 Lamp and Sunlight

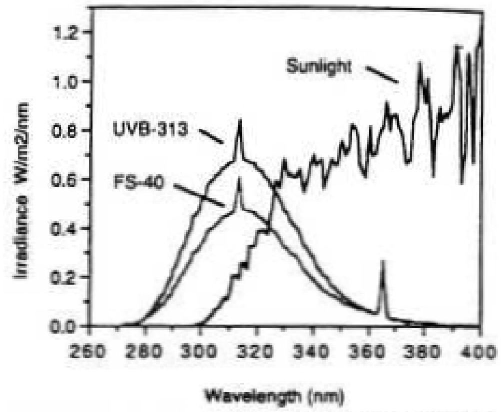

FIG. X1.2 Spectral Power Distributions of UVB Lamps and Sunlight

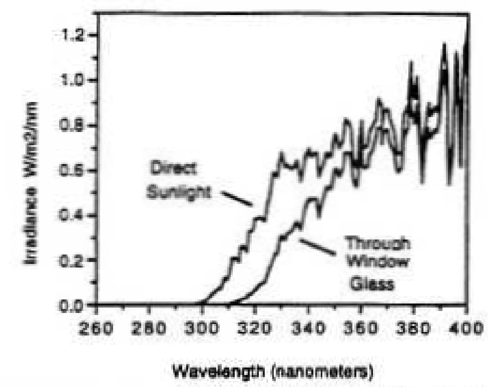

FIG. X1.3 Direct Sunlight and Sunlight Through Window Glass

X1.3.2 *UVA-351 Lamps*—For simulations of sunlight through window glass, UVA-351 lamps are recommended. The UVA-351 is used for these applications because the low end cut-on of this lamp is similar to that of direct sunlight which has been filtered through window glass (Fig. X1.4).

NOTE X1.3—UVB-313 lamps are not recommended for simulations of sunlight through window glass. Most of the emission of UVB-313 lamps is in the short wavelength UV that is filtered very efficiently by glass. Because of this, very little energy from this short wavelength region will reach materials in "behind glass" applications. This is because window glass filters out about 80 % of the energy from UVB-313 lamps, as shown in Fig. X1.5. As a result of filtering out these short wavelengths, its total effective energy is very limited. Further, because there is little longer wavelength energy, the glass-filtered UVB-313 is actually less severe than a UVA Lamp.

X1.4 *Simulations of Exposures Where Glass or Transparent Plastic Forms Part of the Test Specimen*:

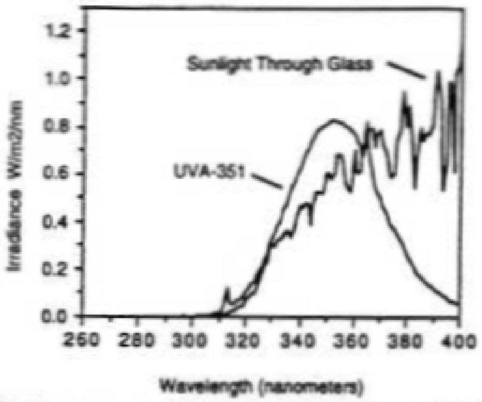

FIG. X1.4 Spectral Power Distributions of UVA-351 Lamp and Sunlight Through Window Glass

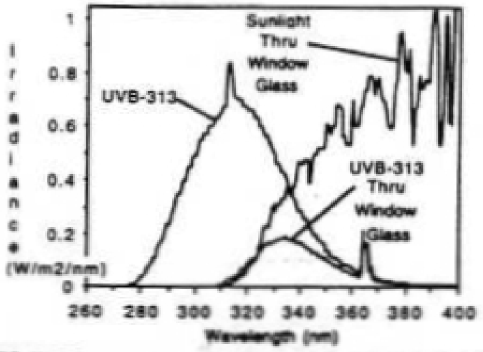

FIG. X1.5 Spectral Power Distributions of Unfiltered UVB-313 Lamp, UVB-313 Through Window Glass, and Sunlight Through Window Glass

X1.4.1 *UVA-340 Lamps*—In some instances (for example, window sealants), glass or transparent plastic is part of the test specimen itself and normally acts as a filter to the light source. In these special cases, the use of UVA-340 lamps is recommended since the glass or plastic will filter the spectrum of the lamp in the same way that it would filter sunlight. Fig. X1.6 compares the spectral power distribution of sunlight filtered through window glass to the spectral power distribution of the UVA-340 lamp, both unfiltered and filtered through window glass.

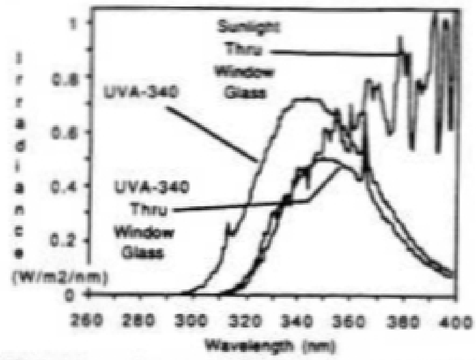

FIG. X1.6 Spectral Power Distributions of Unfiltered UVA-340 Lamp, UVA-340 Through Window Glass, and Sunlight Through Window Glass

NOTE X1.4—UBV-313 lamps are lamps not recommended for exposures where glass or transparent plastic forms part of the test specimen. See Note X1.3.

NOTE X1.5—UVA-351 lamps are not recommended for exposures where glass or transparent plastic forms part of the test specimen. This is because the UVA-351 has a special power distribution in the short wave UV region that is similar to sunlight that has already been filtered by window glass. As shown in Fig. X1.7, using this lamp through window glass or other transparent material further filters out the short wavelength UV and results in a spectrum that is deficient in the short wavelength UV.

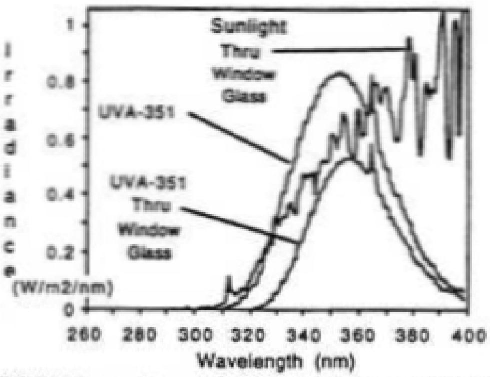

FIG. X1.7 Spectral Power Distributions of Unfiltered UVA-351 Lamp, UVA-351 Through Window Glass, and Sunlight Through Window Glass

X2. EXPOSURE CONDITIONS

X2.1 Any exposure conditions may be used, as long as the exact conditions are detailed in the report. Following are some representative exposure conditions. These are not necessarily preferred and no recommendation is implied. These conditions are provided for reference only (See Table X2.1).

NOTE X2.1—Cycle 1 is a commonly used exposure cycle for coatings and plastics. Cycle 2 has been widely used for coatings. Cycles 3 and 4 have been used for exterior automotive materials. Cycle 5 has been used for roofing materials. Cycle 6 has been used for high irradiance exposures of coatings and plastics. Cycle 7 has been used for thermal shock and for erosion testing of coatings for wood.

NOTE X2.2—When selecting programs of UV exposure followed by condensation, allow at least 2 h per interval to assure attainment of equilibrium.

NOTE X2.3—Surface temperature of specimens is an essential test

TABLE X2.1 Common Exposure Conditions

NOTE 1—Previous editions of ASTM G 154 contained non-mandatory irradiance set points in Table X2.1 that were commonly used in the industry. The previous set points were 0.77 and 1.35 W/m2 at 340 nm for UVA-340 lamps and 0.44, 0.55, and 0.63 W/m2 for UVB-313 lamps. The measurement data used to establish these set points was inaccurate, due to an error in calibration on the part of one manufacturer. It has been found that, for most users, the actual irradiance when running at the previous set points was 11 to 15% higher than the indicated set point. The set points shown in this edition of G 154 do not change the actual irradiances that have been historically used by these users. However, for users of equipment made by another manufacturer, the irradiance control system did not have the measurement inaccuracies described above, so running at the new set points will represent a change in the actual irradiance of the test. If in doubt, users should consult the manufacturer of their device for clarification.

Cycle	Lamp	Typical Irradiance	Approximate Wavelength	Exposure Cycle
1	UVA-340	0.89 W/m²/nm	340 nm	8 h UV at 60 (± 3) °C Black Panel Temperature; 4 h Condensation at 50 (± 3) °C Black Panel Temperature
2	UVB-313	0.71 W/m²/nm	310 nm	4 h UV at 60 (± 3) °C Black Panel Temperature; 4 h Condensation at 50 (± 3) °C Black Panel Temperature
3	UVB-313	0.49 W/m²/nm	310 nm	8 h UV at 70 (± 3) °C Black Panel Temperature; 4 h Condensation at 50 (± 3) °C Black Panel Temperature
4	UVA-340	1.55 W/m²/nm	340 nm	8 h UV at 70 (± 3) °C Black Panel Temperature; 4 h Condensation at 50 (± 3) °C Black Panel Temperature
5	UVB-313	0.62 W/m²/nm	310 nm	20 h UV at 80 (± 3) °C Black Panel Temperature; 4 h Condensation at 50 (± 3) °C Black Panel Temperature
6	UVA-340	1.55 W/m²/nm	340 nm	8 h UV at 60 (± 3) °C Black Panel Temperature; 4 h Condensation at 50 (± 3) °C Black Panel Temperature.
7	UVA-340	1.55 W/m²/nm	340 nm	8 h UV at 60 (± 3) °C Black Panel Temperature; 0.25 h water spray (no light), temperature not controlled; 3.75 h condensation at 50 (± 3) °C Black Panel Temperature
8	UVB-313	28 W/m²	270 to 700 nm	8 h UV at 70 (± 3) °C Black Panel Temperature; 4 h Condensation at 50 (± 3) °C Black Panel Temperature

quantity. Generally, degradation processes accelerate with increasing temperature. The specimen temperature permissible for the accelerated test depends on the material to be tested and on the aging criterion under consideration.

NOTE X2.4—Irradiance data shown is typical. Frequently, the irradiance is not controlled in this type of exposure device.

NOTE X2.5—The light output of fluorescent lamps is affected by the temperature of the air which surrounds the lamps. Consequently, in testers without feed-back-loop control of irradiance, the lamp output will decrease with increasing chamber temperature.

NOTE X2.6—Laboratory ambient temperature may have an effect on the light output of devices without feed-back-loop control of irradiance. Some fluorescent UV devices use laboratory ambient air to cool the lamps and thereby compensate for the drop in light output at higher exposure temperatures (see Note X2.5).

X2.2 For the most consistent results, it is recommended that apparatus without feed-back-loop control of irradiance be operated in an environment in which the ambient temperature is maintained between 18 and 27°C. Apparatus operated in ambient temperatures above or below this range may produce irradiances different from devices operated in the recommended manner.

NOTE X2.7—Fluorescent UV lamps emit relatively little infrared radiation when compared to xenon arc and carbon arc sources. In fluorescent UV apparatus, the primary heating of the specimen surface is by convection from heated air passing across the panel. Therefore, there is a minimal difference between the temperature of an insulated or uninsulated black or white panel thermometer, specimen surface, air in the test chamber, or different colored samples (3).

X2.3 For conversion of test cycles described in Practice G 53 to test cycles described in Practice G 154 see Table X2.2. For operational fluctuations see Table X2.3.

NOTE X2.8—Unless otherwise specified, operate the apparatus to maintain the operational fluctuations specified in Table X2.3 for the parameters in Table X2.1. If the actual operating conditions do not agree with the machine settings after the equipment has stabilized, discontinue the test and correct the cause of the disagreement before continuing.

TABLE X2.2 Conversion of Test Cycles Described in Practice G 53 to Test Cycles Described in Practice G 154

Practice G 53 Test Cycle Description	Corresponding Test Cycle in Practice G 154
Practice G 53 describes one default cycle of 4 hours UV at 60°C, 4 hours condensation at 50°C. The default lamp for this and other cycles is the UVB lamps with peak emission at 313 nm, but fluorescent UVA lamps with peak emission at 343 nm or 351 nm may also be used.	Cycle 2 of Table X2.2 describes the Practice G 53 default cycle using UVB-313 lamps.
Practice G 53 indicated that a cycle of 8 hours UV and 4 hours condensation is widely used. Suggested temperatures during UV exposure were 50°C, 60°C, 70°C	Table X2.2 describes 6 specific exposure cycles that use 8 hours UV followed by 4 hours condensation. These cycles use either UVA-340 or UVB-313 lamps.

TABLE X2.3 Operational Fluctuations On Exposure Conditions

Parameter	Maximum Allowable Deviation from the Set Point at the Control Point Indicated by the Readout of the Calibrated Control Sensor During Equilibrium Operation
Black Panel Temperature	±2.5°C
Irradiance (monitored at 340 nm or monitored at 310 nm)	± .02 W/(m²• nm)
Irradiance (monitored at 270– 700 nm)	± 0.5 W/m²

X3. COMPARISON OF BENCHMARK SOLAR UV SPECTRUM AND CIE 85 TABLE 4 SOLAR SPECTRUM

X3.1 This standard uses a benchmark solar spectrum based on atmospheric conditions that provide for very high level of solar ultraviolet radiation. This benchmark solar spectrum is published in ASTM G 177, Standard Tables for Reference Solar Ultraviolet Spectral Distributions: Hemispherical on 37 degree Tilted Surface. The solar spectrum is calculated using the SMARTS2 solar radiation model.[5,6,7] ASTM Adjunct ADJG0173, SMARTS2 Solar Radiation Model for Spectral Radiation provides the program and documentation for calculating solar spectral irradiance.

X3.2 Previous versions of this standard used CIE 85 Table 4[8] as the benchmark solar spectrum. Table X3.1 compares the basic atmospheric conditions used for the benchmark solar spectrum and the CIE 85 Table 4 solar spectrum.

X3.3 Table X3.2 compares irradiance (calculated using rectangular integration) and relative irradiance for the benchmark solar spectrum and the CIE 85 Table 4 solar spectrum, in the bandpasses used in this standard.

[5] Gueymard, C., "Parameterized Transmittance Model for Direct Beam and Circumsolar Spectral Irradiance," *Solar Energy*, Vol 71, No. 5, 2001, pp. 325-346.

[6] Gueymard, C. A., Myers, D., and Emery, K., "Proposed Reference Irradiance Spectra for Solar Energy Systems Testing," *Solar Energy*, Vol 73, No 6, 2002, pp. 443–467.

[7] Myers, D. R., Emery, K., and Gueymard, C., "Revising and Validating Spectral Irradiance Reference Standards for Photovoltaic Performance Evaluation," Transactions of the American Society of Mechanical Engineers, *Journal of Solar Energy Engineering*, Vol 126, pp 567–574, Feb. 2004.

[8] CIE-Publication Number 85: Recommendations for the Integrated Irradiance and the Spectral Distribution of Simulated Solar Radiation for Testing Purposes, 1st Edition, 1989 (Available from American National Standards Institute, 11 W. 42nd St., 13th Floor, New York, NY 10036).

TABLE X3.1 Comparison of Basic Atmospheric Conditions Used for Benchmark Solar Spectrum and CIE 85 Table 4 Solar Spectrum

Atmospheric Condition	Benchmark Solar Spectrum	CIE 85 Table 4 Solar Spectrum
Ozone (atm-cm)	0.30	0.34
Precipitable water vapor (cm)	0.57	1.42
Altitude (m)	2000	0
Tilt angle	37° facing Equator	0° (horizontal)
Air mass	1.05	1.00
Albedo (ground reflectance)	Light Soil wavelength dependent	Constant at 0.2
Aerosol extinction	Shettle & Fenn Rural (humidity dependent)	Equivalent to Linke Turbidity factor of about 2.8
Aerosol optical thickness at 500 nm	0.05	0.10

TABLE X3.2 Irradiance and Relative Irradiance Comparison for Benchmark Solar Spectrum and CIE 85 Table 4 Solar Spectrum

Bandpass	Benchmark Solar Spectrum	CIE 85Table 4 Solar Spectrum
	Irradiance (W/m²) in stated bandpass	
$\lambda < 290$	0.000	0.000
$290 \leq \lambda \leq 320$	3.748	4.060
$320 < \lambda \leq 360$	25.661	28.450
$360 < \lambda \leq 400$	34.762	42.050
$290 \leq \lambda \leq 400$	64.171	74.560
$290 \leq \lambda \leq 800$	652.300	678.780
	Percent of 290 to 400 nm irradiance	
$\lambda < 290$	0.0 %	0.0 %
$290 < \lambda \leq 320$	5.8 %	5.4 %
$320 < \lambda \leq 360$	40.0 %	38.2 %
$360 < \lambda \leq 400$	54.2 %	56.4 %
	Percent of 290 to 800 nm irradiance	
$290 \leq \lambda \leq 400$	9.8 %	11.0 %

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(1) Mullen, P. A., Kinmonth, R. A., and Searle, N. D., "Spectral Energy Distributions and Aging Characteristics of Fluorescent Sun Lamps and Black Lights," *Journal of Testing and Evaluation*, Vol 3(1), 15–20, 1975.

(2) Fedor, G. R., and Brennan, P. J., "Irradiance Control in Fluorescent UV Exposure Testors," *Accelerated and Outdoor Durability Testing of Organic Materials, ASTM STP 1202*, American Society for Testing and Materials, 1993.

(3) Ketola, W., Robbins, J. S., "UV Transmission of Single Strength Window Glass," *Accelerated and Outdoor Durability Testing of Organic Materials, ASTM STP 1202*, Warren D. Ketola and Douglas Grossman, Editors, American Society for Testing and Materials, 1993.

(4) Fischer, R. M., "Results of Round-Robin Studies of Light- and Water-Exposure Standard Practices," *Accelerated and Outdoor Durability Testing of Organic Materials, ASTM STP 1202*, Warren K. Ketola and Douglas Grossman, Editors, American Society for Testing and Materials, 1993.

(5) Fischer, R. M., and Ketola, W. D., "Surface Temperatures of Materials in Exterior Exposures and Artificial Accelerated Tests," *Accelerated and Outdoor Durability Testing of Organic Materials, ASTM STP 1202*, Warren K. Ketola and Douglas Grossman, Editors, American Society for Testing and Materials, 1993.

Designation: G 155 – 05a

Standard Practice for Operating Xenon Arc Light Apparatus for Exposure of Non-Metallic Materials[1]

This standard is issued under the fixed designation G 155; the number immediately following the designation indicates the year of original adoption or, in the case of revision, the year of last revision. A number in parentheses indicates the year of last reapproval. A superscript epsilon (ε) indicates an editorial change since the last revision or reapproval.

1. Scope

1.1 This practice covers the basic principles and operating procedures for using xenon arc light and water apparatus intended to reproduce the weathering effects that occur when materials are exposed to sunlight (either direct or through window glass) and moisture as rain or dew in actual use. This practice is limited to the procedures for obtaining, measuring, and controlling conditions of exposure. A number of exposure procedures are listed in an appendix; however, this practice does not specify the exposure conditions best suited for the material to be tested.

NOTE 1—Practice G 151 describes performance criteria for all exposure devices that use laboratory light sources. This practice replaces Practice G 26, which describes very specific designs for devices used for xenon-arc exposures. The apparatus described in Practice G 26 iscovered by this practice.

1.2 Test specimens are exposed to filtered xenon arc light under controlled environmental conditions. Different types of xenon arc light sources and different filter combinations are described.

1.3 Specimen preparation and evaluation of the results are covered in ASTM methods or specifications for specific materials. General guidance is given in Practice G 151 and ISO 4892-1. More specific information about methods for determining the change in properties after exposure and reporting these results is described in Practice D 5870.

1.4 The values stated in SI units are to be regarded as the standard.

1.5 *This standard does not purport to address all of the safety concerns, if any, associated with its use. It is the responsibility of the user of this standard to establish appropriate safety and health practices and determine the applicability of regulatory limitations prior to use.*

1.5.1 *Should any ozone be generated from the operation of the lamp(s), it shall be carried away from the test specimens and operating personnel by an exhaust system.*

1.6 This practice is technically similar to the following ISO documents: ISO 4892-2, ISO 11341, ISO 105 B02, ISO 105 B04, ISO 105 B05, and ISO 105 B06.

2. Referenced Documents

2.1 *ASTM Standards:* [2]

D 3980 Practice for Interlaboratory Testing of Paint and Related Materials

D 5870 Practice for Calculating Property Retention Index of Plastics

E 691 Practice for Conducting an Interlaboratory Study to Determine the Precision of a Test Method

G 26 Practice for Operating Light-Exposure Apparatus (Xenon-Arc Type) With and Without Water for Exposure of Nonmetallic Materials

G 113 Terminology Relating to Natural and Artificial Weathering Tests for Nonmetallic Materials

G 151 Practice for Exposing Nonmetallic Materials in Accelerated Test Devices That Use Laboratory Light Sources

2.2 *CIE Standards:*

CIE-Publ. No. 85: Recommendations for the Integrated Irradiance and the Spectral Distribution of Simulated Solar Radiation for Testing Purposes[3]

2.3 *International Standards Organization Standards:*

ISO 1134, Paint and Varnishes—Artificial Weathering Exposure to Artificial Radiation to Filtered Xenon Arc Radiation[4]

ISO 105 B02, Textiles—Tests for Colorfastness—Part B02 Colorfastness to Artificial Light: Xenon Arc Fading Lamp Test[4]

ISO 105 B04, Textiles—Tests for Colorfastness—Part B04 Colorfastness to Artificial Weathering: Xenon Arc Fading Lamp Test[4]

ISO 105 B05, Textiles—Tests for Colorfastness—Part B05

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[1] This practice is under the jurisdiction of ASTM Committee G03 on Weathering and Durability and is the direct responsibility of Subcommittee G03.03 on Simulated and Controlled Exposure Tests.

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[2] For referenced ASTM standards, visit the ASTM website, www.astm.org, or contact ASTM Customer Service at service@astm.org. For *Annual Book of ASTM Standards*volume information, refer to the standard's Document Summary page on the ASTM website.

[3] Available from American National Standards Institute, 11 W. 42d St., 13th Floor, New York, NY 10036).

[4] Available from American National Standards Institute (ANSI), 25 W. 43rd St., 4th Floor, New York, NY 10036.

Detection and Assessment of Photochromism[4]

ISO 105 B06, Textiles—Tests for Colorfastness—Part B06 Colorfastness to Artificial Light at High Temperatures: Xenon Arc Fading Lamp Test[4]

ISO 4892-1, Plastics—Methods of Exposure to Laboratory Light Sources, Part 1, General Guidance[4]

ISO 4892-2, Plastics—Methods of Exposure to Laboratory Light Sources, Part 2, Xenon-Arc Sources[4]

2.4 *Society of Automotive Engineers' Standards:*

SAE J1885, Accelerated Exposure of Automotive Interior Trim Components Using a Controlled Irradiance Water Cooled Xenon Arc Apparatus[5]

SAE J1960, Accelerated Exposure of Automotive Exterior Materials Using a Controlled Irradiance Water Cooled Xenon Arc Apparatus [5]

SAE J2412, Accelerated Exposure of Automotive Interior Trim Components Using a Controlled Irradiance Xenon-Arc Apparatus[5]

SAE J2527 Accelerated Exposure of Automotive Exterior Materials Using a Controlled Irradiance Xenon-Arc Apparatus [5]

3. Terminology

3.1 Definitions—The definitions given in Terminology G 113 are applicable to this practice.

3.2 *Definitions of Terms Specific to This Standard:*

3.2.1 As used in this practice, the term *sunlight* is identical to the terms *daylight* and *solar irradiance, global* as they are defined in Terminology G 113.

4. Summary of Practice

4.1 Specimens are exposed to repetitive cycles of light and moisture under controlled environmental conditions.

4.1.1 Moisture is usually produced by spraying the test specimen with demineralized/deionized water or by condensation of water vapor onto the specimen.

4.2 The exposure condition may be varied by selection of:

4.2.1 Lamp filter(s),

4.2.2 The lamp's irradiance level,

4.2.3 The type of moisture exposure,

4.2.4 The timing of the light and moisture exposure,

4.2.5 The temperature of light exposure,

4.2.6 The temperature of moisture exposure, and

4.2.7 The timing of a light/dark cycle.

4.3 Comparison of results obtained from specimens exposed in the same model of apparatus should not be made unless reproducibility has been established among devices for the material to be tested.

4.4 Comparison of results obtained from specimens exposed in different models of apparatus should not be made unless correlation has been established among devices for the material to be tested.

5. Significance and Use

5.1 The use of this apparatus is intended to induce property changes associated with the end use conditions, including the effects of sunlight, moisture, and heat. These exposures may include a means to introduce moisture to the test specimen. Exposures are not intended to simulate the deterioration caused by localized weather phenomena, such as atmospheric pollution, biological attack, and saltwater exposure. Alternatively, the exposure may simulate the effects of sunlight through window glass. Typically, these exposures would include moisture in the form of humidity.

NOTE 2—**Caution:** Refer to Practice G 151 for full cautionary guidance applicable to all laboratory weathering devices.

5.2 Variation in results may be expected when operating conditions are varied within the accepted limits of this practice. Therefore, no reference shall be made to results from the use of this practice unless accompanied by a report detailing the specific operating conditions in conformance with the Report Section.

5.2.1 It is recommended that a similar material of known performance (a control) be exposed simultaneously with the test specimen to provide a standard for comparative purposes. It is recommended that at least three replicates of each material evaluated be exposed in each test to allow for statistical evaluation of results.

6. Apparatus

6.1 *Laboratory Light Source*—The light source shall be one or more quartz jacketed xenon arc lamps which emit radiation from below 270 nm in the ultraviolet through the visible spectrum and into the infrared. In order for xenon arcs to simulate terrestrial daylight, filters must be used to remove short wavelength UV radiation. Filters to reduce irradiance at wavelengths shorter than 310 nm must be used to simulate daylight filtered through window glass. In addition, filters to remove infrared radiation may be used to prevent unrealistic heating of test specimens that can cause thermal degradation not experienced during outdoor exposures.

6.1.1 The following factors can affect the spectral power distribution of filtered xenon arc light sources as used in these apparatus:

6.1.1.1 Differences in the composition and thickness of filters can have large effects on the amount of short wavelength UV radiation transmitted.

6.1.1.2 Aging of filters can result in changes in filter transmission. The aging properties of filters can be influenced by the composition. Aging of filters can result in a significant reduction in the short wavelength UV emission of a xenon burner.

6.1.1.3 Accumulation of deposits or other residue on filters can effect filter transmission.

6.1.1.4 Aging of the xenon burner itself can result in changes in lamp output. Changes in lamp output may also be caused by accumulation of dirt or other residue in or on the burner envelope.

6.1.2 Follow the device manufacturer's instructions for recommended maintenance.

[5] Available from Society of Automotive Engineers (SAE), 400 Commonwealth Dr., Warrendale, PA 15096-0001.

TABLE 1 Relative Ultraviolet Spectral Power Distribution Specification for Xenon Arc with Daylight Filters[A,B]

Spectral Bandpass Wavelength λ in nm	Minimum Percent[C]	Benchmark Solar Radiation Percent[D,E,F]	Maximum Percent[C]
$\lambda < 290$			0.15
$290 \le \lambda \le 320$	2.6	5.8	7.9
$320 < \lambda \le 360$	28.3	40.0	40.0
$360 < \lambda \le 400$	54.2	54.2	67.5

[A] Data in Table 1 are the irradiance in the given bandpass expressed as a percentage of the total irradiance from 290 to 400 nm. The manufacturer is responsible for determining conformance to Table 1. Annex A1 states how to determine relative spectral irradiance.

[B] The data in Table 1 are based on the rectangular integration of 112 spectral power distributions for water and air cooled xenon-arcs with daylight filters of various lots and ages. The spectral power distribution data is for filters and xenon-burners within the aging recommendations of the device manufacturer. The minimum and maximum data are at least the three sigma limits from the mean for all measurements.

[C] The minimum and maximum columns will not necessarily sum to 100 % because they represent the minimum and maximum for the data used. For any individual spectral power distribution, the calculated percentage for the bandpasses in Table 1 will sum to 100 %. For any individual xenon-lamp with daylight filters, the calculated percentage in each bandpass must fall within the minimum and maximum limits of Table 1. Test results can be expected to differ between exposures using xenon arc devices in which the spectral power distributions differ by as much as that allowed by the tolerances. Contact the manufacturer of the xenon-arc devices for specific spectral power distribution data for the xenon-arc and filters used.

[D] The benchmark solar radiation data is defined in ASTM G 177 and is for atmospheric conditions and altitude chosen to maximize the fraction of short wavelength solar UV. This data is provided for comparison purposes only.

[E] Previous versions of this standard used solar radiation data from Table 4 of CIE Publication Number 85. See Appendix X4 for more information comparing the solar radiation data used in this standard with that for CIE 85 Table 4.

[F] For the benchmark solar spectrum, the UV irradiance (290 to 400 nm) is 9.8 % and the visible irradiance (400 to 800 nm) is 90.2 % expressed as a percentage of the total irradiance from 290 to 800 nm. The percentages of UV and visible irradiances on samples exposed in xenon arc devices may vary due to the number and reflectance properties of specimens being exposed.

TABLE 2 Relative Ultraviolet Spectral Power Distribution Specification for Xenon-Arc with Window Glass Filters[A,B]

Spectral Bandpass Wavelength λ in nm	Minimum Percent[C]	Window Glass Filtered Solar Radiation Percent[D,E,F]	Maximum Percent[C]
$\lambda < 300$		0.0	0.29
$300 \le \lambda \le 320$	0.1	≤ 0.5	2.8
$320 < \lambda \le 360$	23.8	34.2	35.5
$360 < \lambda \le 400$	62.5	65.3	76.1

[A] Data in Table 2 are the irradiance in the given bandpass expressed as a percentage of the total irradiance from 300 to 400 nm. The manufacturer is responsible for determining conformance to Table 2. Annex A1 states how to determine relative spectral irradiance.

[B] The data in Table 2 are based on the rectangular integration of 36 spectral power distributions for water cooled and air cooled xenon-arcs with window glass filters of various lots and ages. The spectral power distribution data is for filters and xenon-burners within the aging recommendations of the device manufacturer. The minimum and maximum data are at least the three sigma limits from the mean for all measurements.

[C] The minimum and maximum columns will not necessarily sum to 100 % because they represent the minimum and maximum for the data used. For any individual spectral power distribution, the calculated percentage for the bandpasses in Table 2 will sum to 100 %. For any individual xenon-lamp with window glass filters, the calculated percentage in each bandpass must fall within the minimum and maximum limits of Table 2. Test results can be expected to differ between exposures using xenon arc devices in which the spectral power distributions differ by as much as that allowed by the tolerances. Contact the manufacturer of the xenon-arc devices for specific spectral power distribution data for the xenon-arc and filters used.

[D] The window glass filtered solar data is for a solar spectrum with atmospheric conditions and altitude chosen to maximize the fraction of short wavelength solar UV (defined in ASTM G 177) that has been filtered by window glass. The glass transmission is the average for a series of single strength window glasses tested as part of a research study for ASTM Subcommittee G3.02.[8] While this data is provided for comparison purposes only, it is desirable for a xenon-arc with window glass filters to provide a spectrum that is a close match to this window glass filtered solar spectrum.

[E] Previous versions of this standard used window glass filtered solar radiation data based on Table 4 of CIE Publication Number 85. See Appendix X4 for more information comparing the solar radiation data used in the standard with that for CIE 85 Table 4.

[F] For the benchmark window glass filtered solar spectrum, the UV irradiance (300 to 400 nm) is 8.2 % and the visible irradiance (400 to 800 nm) is 91.8 % expressed as a percentage of the total irradiance from 300 to 800 nm. The percentages of UV and visible irradiances on samples exposed in xenon arc devices with window glass filters may vary due to the number and reflectance properties of specimens being exposed, and the UV transmission of the window glass filters used.

6.1.3 *Spectral Irradiance of Xenon Arc with Daylight Filters*—Filters are used to filter xenon arc lamp emissions in a simulation of terrestrial sunlight. The spectral power distribution of xenon arcs with new or pre-aged filters[6,7] shall comply with the requirements specified in Table 1.

6.1.4 *Spectral Irradiance of Xenon Arc With Window Glass Filters*—Filters are used to filter xenon arc lamp emissions in a simulation of sunlight filtered through window glass.[8] Table 2 shows the relative spectral power distribution limits for xenon arcs filtered with window glass filters. The spectral power distribution of xenon arcs with new or pre-aged filters shall comply with the requirements specified in Table 2.

6.1.5 *Spectral Irradiance of Xenon Arc With Extended UV Filters*—Filter that transmit more short wavelength UV are sometimes used to accelerate test result. Although this type of filter has been specified in some tests, they transmit significant radiant energy below 300 nm (the typical cut-on wavelength for terrestrial sunlight) and may result in aging processes not occurring outdoors. The spectral irradiance for a xenon arc with extended UV filters shall comply with the requirements of Table 3.

6.1.6 The actual irradiance at the tester's specimen plane is a function of the number of xenon burners used, the power applied to each, and the distance between the test specimens and the xenon burner. If appropriate, report the irradiance and the bandpass in which it was measured.

6.2 *Test Chamber*—The design of the test chamber may vary, but it should be constructed from corrosion resistant material and, in addition to the radiant source, may provide for means of controlling temperature and relative humidity. When required, provision shall be made for the spraying of water on the test specimen, for the formation of condensate on the exposed face of the specimen or for the immersion of the test specimen in water.

6.2.1 The radiation source(s) shall be located with respect to the specimens such that the irradiance at the specimen face complies with the requirements in Practice G 151.

[6] Ketola, W., Skogland, T., Fischer, R., "Effects of Filter and Burner Aging on the Spectral Power Distribution of Xenon Arc Lamps," *Durability Testing of Non-Metallic Materials, ASTM STP 1294*, Robert Herling, Editor, ASTM, Philadelphia, 1995.

[7] Searle, N. D., Giesecke, P., Kinmonth, R., and Hirt, R. C., "Ultraviolet Spectral Distributions and Aging Characteristics of Xenon Arcs and Filters," *Applied Optics*, Vol. No. 8, 1964, pp. 923–927.

[8] Ketola, W., Robbins, J. S., "UV Transmission of Single Strength Window Glass," *Accelerated and Outdoor Durability Testing of Organic Materials, ASTM STP 1202*, Warren D. Ketola and Douglas Grossman, Editors, ASTM, Philadelphia, 1993.

TABLE 3 Relative Ultraviolet Spectral Power Distribution Specification for Xenon Arc with Extended UV Filters[A,B]

Spectral Bandpass Wavelength λ in nm	Minimum Percent[C]	Benchmark Solar Radiation Percent[D,E,F]	Maximum Percent[C]
$250 < \lambda < 290$	0.1		0.7
$290 \le \lambda \le 320$	5.0	5.8	11.0
$320 < \lambda \le 360$	32.3	40.0	37.0
$360 < \lambda \le 400$	52.0	54.2	62.0

[A] Data in Table 3 are the irradiance in the given bandpass expressed as a percentage of the total irradiance from 250 to 400 nm. The manufacturer is responsible for determining conformance to Table 3. Annex A1 states how to determine relative spectral irradiance.

[B] The data in Table 3 are based on the rectangular integration of 81 spectral power distributions for water cooled and air cooled xenon-arcs with extended UV filters of various lots and ages. The spectral power distribution data is for filters and xenon-burners within the aging recommendations of the device manufacturer. The minimum and maximum data are at least the three sigma limits from the mean for all measurements.

[C] The minimum and maximum columns will not necessarily sum to 100 % because they represent the minimum and maximum for the data used. For any individual spectral power distribution, the calculated percentage for the bandpasses in Table 3 will sum to 100 %. For any individual xenon-arc lamp with extended UV filters, the calculated percentage in each bandpass must fall within the minimum and maximum limits of Table 3. Test results can be expected to differ between exposures using xenon arc devices in which the spectral power distributions differ by as much as that allowed by the tolerances. Contact the manufacturer of the xenon-arc devices for specific spectral power distribution data for the xenon-arc and filters used.

[D] The benchmark solar radiation data is defined in ASTM G 177 and is for atmospheric conditions and altitude chosen to maximize the fraction of short wavelenght solar UV. This data is provided for comparison purposes only.

[E] Previous versions of this standard used solar radiation data from Table 4 of CIE Publication Number 85. See Appendix X4 for more information comparing the solar radiation data used in the standard with that for CIE 85 Table 4.

[F] For the benchmark solar spectrum, the UV irradiance (290 to 400 nm) is 9.8 % and the visible irradiance (400 to 800 nm) is 90.2 % expressed as a percentage of the total irradiance from 290 to 800 nm. The percentages of UV and visible irradiances on samples exposed in xenon arc devices may vary due to the number and reflectance properties of specimens being exposed.

6.3 *Instrument Calibrition*—To ensure standardization and accuracy, the instruments associated with the exposure apparatus (that is, timers, thermometers, wet bulb sensors, dry bulb sensors, humidity sensors, UV sensors, radiometers) require periodic calibration to ensure repeatability of test results. Whenever possible, calibration should be traceable to national or international standards. Calibration schedule and procedure should be in accordance with manufacturer's instructions.

6.4 *Radiometer*—The use of a radiometer to monitor and control the amount of radiant energy received at the specimen is recommended. If a radiometer is used, it shall comply with the requirements in Practice ASTM G 151.

6.5 *Thermometer*—Either insulated or un-insulated black or white panel thermometers may be used. Thermometers shall conform to the descriptions found in Practice G 151. The type of thermometer used, the method of mounting on specimen holder, and the exposure temperature shall be stated in the test report.

6.5.1 The thermometer shall be mounted on the specimen rack so that its surface is in the same relative position and subjected to the same influences as the test specimens.

6.5.2 Some specifications may require chamber air temperature control. Positioning and calibration of chamber air temperature sensors shall be in accordance with the descriptions found in Practice G 151.

6.6 *Moisture*—The test specimens may be exposed to moisture in the form of water spray, condensation, immersion, or high humidity.

6.6.1 *Water Spray*—The test chamber may be equipped with a means to introduce intermittent water spray onto the front or the back of the test specimens, under specified conditions. The spray shall be uniformly distributed over the specimens. The spray system shall be made from corrosion resistant materials that do not contaminate the water employed.

6.6.1.1 *Quality of Water for Sprays and Immersion*—Spray water must have a conductivity below 5 μS/cm, contain less than 1-ppm solids, and leave no observable stains or deposits on the specimens. Very low levels of silica in spray water can cause significant deposits on the surface of test specimens. Care should be taken to keep silica levels below 0.1 ppm. In addition to distillation, a combination of deionization and reverse osmosis can effectively produce water of the required quality. The pH of the water used should be reported. See Practice G 151 for detailed water quality instructions.

6.6.1.2 *Condensation*—A spray system designed to cool the specimen by spraying the back surface of the specimen or specimen substrate may be required when the exposure program specifies periods of condensation.

6.6.2 *Relative Humidity*—The test chamber may be equipped with a means to measure and control the relative humidity. Such instruments shall be shielded from the lamp radiation.

6.6.3 *Water Immersion*—The test chamber may be equipped with a means to immerse specimens in water under specified conditions. The immersion system shall be made from corrosion resistant materials that do not contaminate the water employed.

6.7 *Specimen Holders*—Holders for test specimens shall be made from corrosion resistant materials that will not affect the test results. Corrosion resistant alloys of aluminum or stainless steel have been found acceptable. Brass, steel, or copper shall not be used in the vicinity of the test specimens.

6.7.1 The specimen holders are typically, but not necessarily, mounted on a revolving cylindrical rack that is rotated around the lamp system at a speed dependent on the type of equipment and that is centered both horizontally and vertically with respect to the exposure area.

6.7.2 Specimen holders may be in the form of an open frame, leaving the back of the specimen exposed, or they may provide the specimen with a solid backing. Any backing used may affect test results and shall be agreed upon in advance between the interested parties.

6.7.3 Specimen holders may rotate on their own axis. When these holders are used, they may be filled with specimens placed back to back. Rotation of the holder on its axis alternately exposes each specimen to direct radiation from the xenon burner.

6.8 *Apparatus to Assess Changes in Properties*—Use the apparatus required by the ASTM or other standard that describes determination of the property or properties being monitored.

7. Test Specimen

7.1 Refer to Practice G 151.

8. Test Conditions

8.1 Any exposure conditions may be used as long as the exact conditions are detailed in the report. Appendix X1 lists some representative exposure conditions. These are not necessarily preferred and no recommendation is implied. These conditions are provided for reference only.

9. Procedure

9.1 Identify each test specimen by suitable indelible marking, but not on areas to be used in testing.

9.2 Determine which property of the test specimens will be evaluated. Prior to exposing the specimens, quantify the appropriate properties in accordance with recognized international standards. If required (for example, destructive testing), use unexposed file specimens to quantify the property. See Practice D 5870 for detailed guidance.

9.3 *Mounting of Test Specimens*—Attach the specimens to the specimen holders in the equipment in such a manner that the specimens are not subject to any applied stress. To assure uniform exposure conditions, fill all of the spaces, using blank panels of corrosion resistant material if necessary.

NOTE 3—Evaluation of color and appearance changes of exposed materials must be made based on comparisons to unexposed specimens of the same material which have been stored in the dark. Masking or shielding the face of test specimens with an opaque cover for the purpose of showing the effects of exposure on one panel is not recommended. Misleading results may be obtained by this method, since the masked portion of the specimen is still exposed to temperature and humidity that in many cases will affect results.

9.4 *Exposure to Test Conditions*—Program the selected test conditions to operate continuously throughout the required number of repetitive cycles. Maintain these conditions throughout the exposure. Interruptions to service the apparatus and to inspect specimens shall be minimized.

9.5 *Specimen Repositioning*—Periodic repositioning of the specimens during exposure is not necessary if the irradiance at the positions farthest from the center of the specimen area is at least 90 % of that measured at the center of the exposure area. Irradiance uniformity shall be determined in accordance with Practice G 151.

9.5.1 If irradiance at positions farthest from the center of the exposure area is between 70 and 90 % of that measured at the center, one of the following three techniques shall be used for specimen placement.

9.5.1.1 Periodically reposition specimens during the exposure period to ensure that each receives an equal amount of radiant exposure. The repositioning schedule shall be agreed upon by all interested parties.

9.5.1.2 Place specimens only in the exposure area where the irradiance is at least 90 % of the maximum irradiance.

9.5.1.3 To compensate for test variability, randomly position replicate specimens within the exposure area that meets the irradiance uniformity requirements as defined in section 9.5.1.

9.6 *Inspection*—If it is necessary to remove a test specimen for periodic inspection, take care not to handle or disturb the test surface. After inspection, the test specimen shall be returned to the test chamber with its test surface in the same orientation as previously tested.

9.7 *Apparatus Maintenance*—The test apparatus requires periodic maintenance to maintain uniform exposure conditions. Perform required maintenance and calibration in accordance with manufacturer's instructions.

9.8 Expose the test specimens for the specified period of exposure. See Practice G 151 for further guidance.

9.9 At the end of the exposure, quantify the appropriate properties in accordance with recognized international standards and report the results in conformance with Practice G 151.

NOTE 4—Periods of exposure and evaluation of test results are addressed in Practice G 151.

10. Report

10.1 The test report shall conform to Practice G 151.

11. Precision and Bias

11.1 *Precision*:

11.1.1 The repeatability and reproducibility of results obtained in exposures conducted according to this practice will vary with the materials being tested, the material property being measured, and the specific test conditions and cycles that are used. In round-robin studies conducted by Subcommittee G03.03, the 60° gloss values of replicate PVC tape specimens exposed in different laboratories using identical test devices and exposure cycles showed significant variability. The variability shown in these round-robin studies restricts the use of "absolute specifications" such as requiring a specific property level after a specific exposure period.

11.1.2 If a standard or specification for general use requires a definite property level after a specific time or radiant exposure in an exposure test conducted according to this practice, the specified property level shall be based on results obtained in a round-robin that takes into consideration the variability due to the exposure and the test method used to measure the property of interest. The round-robin shall be conducted according to Practice E 691 or Practice D 3980 and shall include a statistically representative sample of all laboratories or organizations who would normally conduct the exposure and property measurement.

11.1.3 If a standard or specification for use between two or three parties requires a definite property level after a specific time or radiant exposure in an exposure test conducted according to this practice, the specified property level shall be based on statistical analysis of results from at least two separate, independent exposures in each laboratory. The design of the experiment used to determine the specification shall take into consideration the variability due to the exposure and the test method used to measure the property of interest.

11.1.4 The round-robin studies cited in 11.1.1 demonstrated that the gloss values for a series of materials could be ranked with a high level of reproducibility between laboratories. When reproducibility in results from an exposure test conducted according to this practice have not been established through round-robin testing, performance requirements for materials shall be specified in terms of comparison (ranked) to a control material. The control specimens shall be exposed simultaneously with the test specimen(s) in the same device. The specific control material used shall be agreed upon by the concerned parties. Expose replicates of the test specimen and the control specimen so that statistically significant performance differences can be determined.

11.2 *Bias*—Bias cannot be determined because no acceptable standard weathering reference materials are available.

12. Keywords

12.1 accelerated; accelerated weathering; durability; exposure; laboratory weathering; light; lightfastness; non-metallic materials; temperature; ultraviolet; weathering; xenon arc

ANNEX

A1. DETERMINING CONFORMANCE TO RELATIVE SPECTRAL POWER DISTRIBUTION TABLES

(Mandatory Information for Equipment Manufacturers)

A1.1 Conformance to the relative spectral power distribution tables is a design parameter for xenon-arc source with the different filters provided. Manufacturers of equipment claiming conformance to this standard shall determine conformance to the spectral power distribution tables for all lamp/filter combinations provided, and provide information on maintenance procedures to minimize any spectral changes that may occur during normal use.

A1.2 The relative spectral power distribution data for this standard were developed using the rectangular integration technique. Eq A1.1 is used to determine the relative spectral irradiance using rectangular integration. Other integration techniques can be used to evaluate spectral power distribution data, but may give different results. When comparing relative spectral power distribution data to the spectral power distribution requirements of this standard, use the rectangular integration technique.

A1.3 To determine whether a specific lamp for a xenon-arc device meets the requirements of Table 1, Table 2, or Table 3, measure the spectral power distribution from 250 nm to 400 nm. Typically, this is done at 2 nm increments. If the manufacturer's spectral measurement equipment cannot measure wavelengths as low as 250 nm, the lowest measurement wavelength must be reported. The lowest wavelength measured shall be no greater than 270 nm. For determining conformance to the relative spectral irradiance requirements for a xenon-arc with extended UV filters, measurement from 250 nm to 400 nm is required. The total irradiance in each wavelength bandpass is then summed and divided by the specified total UV irradiance according to Eq A1.1. Use of this equation requires that each spectral interval must be the same (for example, 2 nm) throughout the spectral region used.

$$I_R = \frac{\sum_{\lambda_i=A}^{\lambda_i=B} E_{\lambda_i}}{\sum_{\lambda_i=C}^{\lambda_i=400} E_{\lambda_i}} \times 100 \quad \text{(A1.1)}$$

where:

I_R = relative irradiance in percent,
E = irradiance at wavelength λ_i (irradiance steps must be equal for all bandpasses),
A = lower wavelength of wavelength bandpass,
B = upper wavelength of wavelength bandpass,
C = lower wavelength of total UV bandpass used for calculating relative spectral irradiance (290 nm for daylight filters, 300 nm for window glass filters, or 250 nm for extended UV filters), and
λ_i = wavelength at which irradiance was measured.

APPENDIXES

(Nonmandatory Information)

X1. APPARATUS WITH AIR-COOLED XENON ARC LAMPS

X1.1 This test apparatus uses one or more air-cooled xenon arc lamps as the source of radiation. Different type and different size lamps operating in different wattage ranges may be utilized in different sizes and types of apparatus.

X1.2 The radiation system consists of either one or more xenon-arc lamps, depending on the type of apparatus. A heat-absorbing system may be used.

X2. APPARATUS WITH WATER-COOLED XENON ARC LAMPS

X2.1 The test apparatus uses a water-cooled xenon arc lamp as the source of radiation. Different size lamps operating in different wattage ranges may be utilized in different sizes and types of apparatus.

X2.2 The xenon-arc lamp used consists of a xenon burner tube, an inner filter of glass or quartz, an outer glass filter, and the necessary accessories. To cool the lamp, distilled or deionized water is circulated over the burner tube and then directed out of the lamp between the inner and outer glass filters.

X3. EXPOSURE CONDITIONS

X3.1 Any exposure conditions may be used, as long as the exact conditions are detailed in the report. Following are some representative exposure conditions. These are not necessarily preferred and no recommendation is implied. These conditions are provided for reference only (see Table X3.1).

NOTE X3.1—These exposure conditions are brief summaries of the actual exposure procedures. Consult the applicable test method or material specification for detailed operating instructions and procedures. Historical convention has established Cycle 1 as a very commonly used exposure cycle. Other cycles may give a better simulation of the effects of outdoor

TABLE X3.1 Common Exposure Conditions

Cycle	Filter	Irradiance	Wavelength	Exposure Cycle
1	Daylight	0.35 W/m^2· nm	340 nm	102 min light at 63°C Black Panel Temperature 18 min light and water spray (air temp. not controlled)
2	Daylight	0.35 W/m^2· nm	340 nm	102 min light at 63 °C Uninsulated Black Panel Temperature 18 min light and water spray (air temp. not controlled); 6 h dark at 95 (±4.0) % RH, at 24 °C Uninsulated Black Panel Temperature
3	Daylight	0.35 W/m^2· nm	340 nm	1.5 h light, 70 % RH, at 77 °C Black Panel Temperature 0.5 h light and water spray (air temp. not controlled)
4	Window Glass	0.30 W/m^2· nm	340 nm	100 % light, 55 % RH, at 55° C Black Panel Temperature
5	Window Glass	1.10 W/m^2· nm	420 nm	102 min light, 35 % RH, at 63 °C Black Panel Temperature 18 min light and water spray (air temp. not controlled)
6	Window Glass	1.10 W/m^2· nm	420 nm	3.8 h light, 35 % RH, at 63 °C Black Panel Temperature 1 h dark, 90 % RH, at 43 ° C Black Panel Temperature
7	Extended UV	0.55 W/m^2·nm	340 nm	40 min light, 50 (±5.0) % RH, at 70 (±2) °C Black Panel Temperature and 47 (±2) °C Chamber Air Temperature 20 min light and water spray on specimen face; 60 min light, 50 (±5.0) % RH, at 70 (±2) °C Black Panel Temperature; and 47 (±2) °C Chamber Air Temperature 60 min dark and water spray on specimen back, 95 (±5.0) % RH, 38 (±2) °C Black Panel Temperature and 38 (±2) °C Chamber Air Temperature
7A	Daylight	0.55 W/m^2·nm	340 nm	40 min light, 50 (±5.0) % RH, at 70 (±2) °C Black Panel Temperature and 47 (±2) °C Chamber Air Temperature 20 min light and water spray on specimen face; 60 min light, 50 (±5.0) % RH, at 70 (±2) °C Black Panel Temperature; and 47 (±2) °C Chamber Air Temperature 60 min dark and water spray on specimen front and back, 95 (±5.0) % RH, 38 (±2) °C Black Panel Temperature and 38 (±2) °C Chamber Air Temperature
8	Extended UV	0.55 W/m^2·nm	340 nm	3.8 h light, 50 (±5.0) % RH, at 89 (±3) °C Black Panel Temperature and 62 (±2) °C Chamber Air Temperature 1.0 h dark, 95 (±5.0) % RH, at 38 (±2) °C Black Panel Temperature and 38 (±2) °C Chamber Air Temperature
9	Daylight	180 W/m^2(at 300–400 nm)	300–400 nm	102 min light at 63 °C Black Panel Temperature 18 min light and water spray (temperature not controlled)
10	Window Glass	162 W/m^2(at 300–400 nm)	300–400 nm	100 % light, 50 % RH, at 89 °C Black Panel Temperature
11	Window Glass	1.5 W/m^2· nm	420 nm	Continuous light at 63 °C uninsulated black panel temperature, 30 % RH
12	Daylight	0.35 W/m^2· nm	340 nm	18 h consisting of continuous light at 63°C uninsulated black panel temperature 30 % RH 6 h dark at 90 % RH, at 35 °C dry bulb temperature

exposure. Cycle 3 has been used for exterior grade textile materials. Cycle 4 has been used for indoor plastics. Cycles 5 and 6 have been commonly used for indoor textile materials. Cycle 7 has been used for automotive exterior materials. Cycle 8 has been used for automotive interior components.

NOTE X3.2—Cycle 7 corresponds to the test cycles specified in SAE J2527and to SAE J1960. Cycle 8 corresponds to the test cycles specified in SAE J2412 and SAE J1885. Consult the appropriate test procedure for detailed cycle descriptions, operating instructions, and a description of the filters used in this application. The filter system specified in these procedures is characterized in .

NOTE X3.3—More complex cycles may be programmed in conjunction with dark periods that allow high relative humidities and the formation of condensate at elevated chamber temperatures. Condensation may be produced on the face of the specimens by spraying the rear side of the specimens to cool them below the dew point.

NOTE X3.4—For special tests, a high operating temperature may be desirable, but this will increase the tendency for thermal degradation to adversely influence the test results.

NOTE X3.5—Surface temperature of specimens is an essential test quantity. Generally, degradation processes accelerate with increasing temperature. The specimen temperature permissible for the accelerated test depends on the material to be tested and on the aging criterion under consideration.

NOTE X3.6—The relative humidity of the air as measured in the test chamber is not necessarily equivalent to the relative humidity of the air very close to the specimen surface. This is because test specimens having varying colors and thicknesses may be expected to vary in temperature.

X3.2 Unless otherwise specified, operate the apparatus to maintain the operational fluctuations specified in Table X3.2 for the parameters in Table X3.1. If the actual operating conditions do not agree with the machine settings after the equipment has stabilized, discontinue the test and correct the cause of the disagreement before continuing.

TABLE X3.2 Operational Fluctuations on Exposure Conditions

Parameter	Maximum Allowable Deviations from the Set Point at the Control Point Indicated by the Readout of the Calibrated Control Sensor During Equilibrium Operation
Black Panel Temperature	± 2.5 °C
Chamber Air Temperature	± 2 °C
Relative Humidity	± 5 %
Irradiance (monitored at 340 nm)	± 0.02 W/ (m²· nm)
Irradiance (monitored at 420 nm)	± 0.02 W/ (m²· nm)
Irradiance (monitored at 300–400 nm)	± 2 W/m²

NOTE X3.7—Set points and operational fluctuations could either be listed independently of each other, or they could be listed in the format: Set point ± operational fluctuations. The set point is the target condition for the sensor used at the operational control point as programmed by the user. Operational fluctuations are deviations from the indicated set point at the control point indicated by the readout of the calibrated control sensor during equilibrium operation and do not include measurement uncertainty. At the operational control point, the operational fluctuation can exceed no more than the listed value at equilibrium. When a standard calls for a particular set point, the user programs that exact number. The operational fluctuations specified with the set point do not imply that the user is allowed to program a set point higher or lower than the exact set point specified..

X3.3 For conversion of test cycles from G26 to G155 see Table X3.3.

G 155 – 05a

TABLE X3.3 Conversion of Test Cycles from G26 to G155

G26 Test Cycle Description for	Corresponding Test Cycle In G155
G 26, Method A — Continuous light with intermittent water spray The following test cycle is the only specific condition described 102 min light only (uninsulated black panel temperature at 63 ± 3°C 18 min light + water spray The type of filter and realtive humidity during the light period are not specified	Three cycles in G155, Table X3.1 use continuous light and the same water spray times as the conditions described in G26, Method A Cycle 1 uses daylight filters with 340 nm irradiance controlled at 0.35W/m^2/nm (the suggested minimum 340 nm irradiance for daylight filters in G26, Method A) Cycle 5 uses window glass filters with 420 nm irradiance controlled at 1.10W/m^2/nm (the suggested minimum 340 nm irradiance for window glass filters in G26 is 0.7W/m^2/nm Cycle 9 uses daylight filters and 340 nm irradiance controlled at 1.55 W/m^2/nm (180 W/m^2/nm from 300–400 nm).
G26– Method B — alternate exposure to light and dark and intermittent exposure to water spray No specific light/dark/water cycle described The only conditions during the light period that are described are those of Method A. The length of dark period is not specified, nor are temperature or relative humidity conditions during the dark period.	G155, Table X3.1 describes several specific cycles that combine light/dark periods with periods of water spray Cycle 2 in Table X3.1 has has an 18h light period using the same conditions described in G26, Method A followed by a 6 h dark period at a very high realtive humidity
G26– Method C — continuous exposure to light with no water spray Uses window glass filters Uninsulated black panel temperature is 63 ± 3°C, relative humidity is 30 ± 5% Typical irradiance is 1.5 W/m^2/nm	G155, Table X3.1, Cycle 11
G26– Method D — alternate exposure to light and darkness without water spray No specific periods of light/dark are described Type of filter not specified Irradiance is not specified. Suggested minimum irradiance is 0.35 W/m^2 at 340 nm with daylight filters or 0.7 W/m^2 at 420 nm with window glass filters RH controlled to 35 ± 5% during light period Dark cycle requires a dry bulb temperature of 35 ± 3°C and 90 ± 5% RH	G153, Table X3.1 Cycle 12

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TABLE X3.4 Comparison of Basic Atmospheric Conditions Used for Benchmark Solar Spectrum and CIE 85 Table 4 Solar Spectrum

Atmospheric Condition	Benchmark Solar Spectrum	CIE 85 Table 4 Solar Spectrum
Ozone (atm-cm)	0.30	0.34
Precipitable water vapor (cm)	0.57	1.42
Altitude (m)	2000	0
Tilt angle	37° facing Equator	0° (horizontal)
Air mass	1.05	1.00
Albedo (ground reflectance)	Light Soil wavelength dependent	Constant at 0.2
Aerosol extinction	Shettle & Fenn Rural (humidity dependent)	Equivalent to Linke Turbidity factor of about 2.8
Aerosol optical thickness at 500 nm	0.05	0.10

TABLE X3.5 Irradiance and Relative Irradiance Comparison for Benchmark Solar Spectrum and CIE 85 Table 4 Soalr Spectrum

Bandpass	Benchmark Solar Spectrum	CIE 85 Table 4 Solar Spectrum
	Irradiance (W/m²) in stated bandpass	
λ < 290	0.000	0.000
290 ≤ λ ≤ 320	3.748	4.060
320 < λ ≤ 360	25.661	28.450
360 < λ ≤ 400	34.762	42.050
290 ≤ λ ≤ 400	64.171	74.560
290 ≤ λ ≤ 800	652.300	678.780
	Percent of 290 to 400 nm irradiance	
λ < 290	0.0 %	0.0 %
290 < λ ≤ 320	5.8 %	5.4 %
320 < λ ≤ 360	40.0 %	38.2 %
360 < λ ≤ 400	54.2 %	56.4 %
	Percent of 290 to 800 nm irradiance	
290 ≤ λ ≤ 400	9.8 %	11.0 %

X4. COMPARISON OF BENCHMARK SOLAR UV SPECTRUM AND CIE 85 TABLE 4 SOLAR SPECTRUM

X4.1 This standard uses a benchmark solar spectrum based on atmospheric conditions that provide for a very high level of solar ultraviolet radiation. This benchmark solar spectrum is published in ASTM G 177, Standard Tables for Reference Solar Ultraviolet Spectral Distributions: Hemispherical on 37 degree Tilted Surface. The solar spectrum is calculated using the SMARTS2 solar radiation model.[9,10,11] ASTM Adjunct ADJG0173, SMARTS2 Solar Radiation Model for Spectral Radiation provides the program and documentation for calculating solar spectral irradiance.

X4.2 Previous versions of this standard used CIE 85 Table 4 as the benchmark solar spectrum. Table X3.4 compares the basic atmospheric conditions used for the benchmark solar spectrum and CIE 85 Table 4 solar spectrum.

X4.3 Table X3.5 compares irradiance (calculated using rectangular integration) and relative irradiance for the benchmark solar spectrum and CIE 85 Table 4 solar spectrum, in the bandpasses used in this standard.

[9] Gueymard, C., "Parameterized Transmittance Model for Direct Beam and Circumsolar Spectral Irradiance," *Solar Energy*, Vol 71, No. 5, 2001, pp. 325-346.

[10] Gueymard, C. A., Myers, D., and Emery, K., "Proposed Reference Irradiance Spectra for Solar Energy Systems Testing," *Solar Energy*, Vol 73, No 6, 2002, pp. 443-467.

[11] Myers, D. R., Emery, K., and Gueymard, C., "Revising and Validating Spectral Irradiance Reference Standards for Photovoltaic Performance Evaluation," Transactions of the American Society of Mechanical Engineers, *Journal of Solar Energy Engineering*, Vol 126, pp 567–574, Feb. 2004

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AMERICAN SOCIETY FOR TESTING AND MATERIALS
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Standard Practice for Conducting Tests on Paint and Related Coatings and Materials Using a Fluorescent UV-Condensation Light- and Water-Exposure Apparatus[1]

This standard is issued under the fixed designation D 4587; the number immediately following the designation indicates the year of original adoption or, in the case of revision, the year of last revision. A number in parentheses indicates the year of last reapproval. A superscript epsilon (ε) indicates an editorial change since the last revision or reapproval.

1. Scope

1.1 This practice covers the selection of test conditions from Practice G 53 to be employed for exposure testing of paint and related coatings and materials.

1.2 *This standard does not purport to address all of the safety problems associated with its use. It is the responsibility of the user of this standard to establish appropriate safety and health practices and determine the applicability of regulatory limitations prior to use.*

2. Referenced Documents

2.1 *ASTM Standards:*

D 358 Specification for Wood to Be Used As Panels in Weathering Tests of Coatings[2]
D 523 Test Method for Specular Gloss[2]
D 609 Methods for Preparation of Steel Panels for Testing Paint, Varnish, Lacquer, and Related Products[2]
D 610 Test Method for Evaluating Degree of Rusting on Painted Steel Surfaces[2]
D 659 Method of Evaluating Degree of Chalking of Exterior Paints[2]
D 660 Test Method for Evaluating Degree of Checking of Exterior Paints[2]
D 661 Test Method for Evaluating Degree of Cracking of Exterior Paints[2]
D 662 Test Method for Evaluating Degree of Erosion of Exterior Paints[2]
D 714 Test Method for Evaluating Degree of Blistering of Paints[2]
D 772 Test Method for Evaluating Degree of Flaking (Scaling) of Exterior Paints[2]
D 823 Test Methods for Producing Films of Uniform Thickness of Paint, Varnish, and Related Products on Test Panels[2]
D 1005 Test Methods for Measurement of Dry Film Thickness of Organic Coatings Using Micrometers[2]
D 1186 Test Methods for Nondestructive Measurement of Dry Film Thickness of Nonmagnetic Coatings Applied to a Ferrous Base[2]
D 1400 Test Method for Nondestructive Measurement of Dry Film Thickness of Nonconductive Coatings Applied to a Nonferrous Metal Base[2]
D 1654 Method for Evaluation of Painted or Coated Specimens Subjected to Corrosive Environments[2]
D 1729 Practice for Visual Evaluation of Color Differences of Opaque Materials[3]
D 1730 Practices for Preparation of Aluminum and Aluminum-Alloy Surfaces for Painting[4]
D 1731 Practices for Preparation of Hot-Dip Aluminum Surfaces for Painting[4]
D 1732 Practices for Preparation of Magnesium Alloy Surfaces for Painting[4]
D 2092 Practice for Preparation of Zinc-Coated (Galvanized) Steel Surfaces for Painting[2]
D 2244 Test Method for Calculation of Color Differences from Instrumentally Measured Color Coordinates[3]
D 2616 Test Method for Evaluation of Visual Color Difference With a Gray Scale[5]
D 4214 Test Methods for Evaluating Degree of Chalking of Exterior Paint Films[2]
E 97 Test Method for Directional Reflectance Factor, 45-deg 0-deg, of Opaque Specimens by Broad-Band Filter Reflectometry[3]
G 53 Practice for Operating Light- and Water-Exposure Apparatus (Fluorescent UV-Condensation Type) for Exposure of Nonmetallic Materials[3]

3. Significance and Use

3.1 Organic coatings on exterior exposure are subjected to attack by degrading elements of the weather, particularly ultraviolet light, oxygen, and water. This practice may be used for evaluating the behavior of films exposed in apparatus that produces ultraviolet radiation, high temperatures, and water condensation on the films. This apparatus is used to make an early materials comparison of the exterior exposure quality of paints. However, light sources, such as the fluorescent UV lamp, that emit a significant amount of radiation at wavelengths shorter than those in natural sunlight, may cause results that lead to unrealistic evaluations of weathering properties.

3.2 As no single light exposure apparatus, with or without water, can be specified as a direct simulation of natural exposure, this practice does not imply expressly, or otherwise, a specific correlation with outdoor exposure. It has, however, been useful in many instances.

3.3 Since climatic conditions vary with respect to time,

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[1] This practice is under the jurisdiction of ASTM Committee D-1 on Paint and Related Coatings and Materials and is the direct responsibility of Subcommittee D01.27 on Accelerated Testing.

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[2] *Annual Book of ASTM Standards*, Vol 06.01.

[3] *Annual Book of ASTM Standards*, Vol 14.02.

[4] *Annual Book of ASTM Standards*, Vols 02.05 and 06.01.

[5] *Annual Book of ASTM Standards*, Vols 06.01 and 14.02.

geography, and topography, it may be expected that the effects of natural exposure will vary accordingly. All materials are not affected equally by the same environment. Results obtained by use of this practice should not be represented as equivalent to those of any outdoor weathering test unless the degree of quantitative correlation has been established for the material in question.

3.4 Variations in results may be expected when operating conditions among similar type instruments vary within accepted limits of this standard procedure.

4. Test Specimens

4.1 Unless otherwise agreed upon, choose panels that meet the applicable base panel requirements specified in Standards D 358, D 609, D 1730, D 1731, D 1732, or D 2092. Select panel sizes suitable for exhibiting the failure mode to be observed.

4.2 Apply the coatings to flat panels with the base panel material, method of application, coating system, film thickness, and method of drying consistent with the anticipated end use, or as mutually agreed upon between the producer and the user. If it's not possible to test *flat* samples, you may need to take special precautions to ensure that (*1*) the sample holders seal behind the samples so that the water vapor does not escape from the test chamber, and (*2*) the closest part of the samples to the UV lamps is at the 50-mm distance specified in Practice G 53. If part of the sample is closer to the lamps, it will be subject to more intense UV exposure.

4.3 Unless otherwise agreed upon, coat test panels in accordance with Test Methods D 823 and measure the film thickness in accordance with an appropriate procedure selected from Test Methods D 1005, D 1186, or D 1400. Nondestructive methods are preferred because panels so measured do not need to be repaired.

4.4 Unless otherwise specified, before exposing coated panels in the apparatus, condition them at 73.5 ± 3.5°F (23 ± 2°C) and 50 ± 5 % relative humidity for one of the following periods in accordance with the type of coating:

Baked coatings	24 h
Radiation-cured coatings	24 h
All other coatings	7 days minimum

5. Apparatus

5.1 *Fluorescent UV/Condensation Apparatus*, complying with Practice G 53.[6]

6. Procedure

6.1 Place panels within the 8.25 by 35.35-in. (210 by 900-mm) area as described in Practice G 53. Reposition the panels on a regular schedule as described in Practice G 53 to minimize any effects from temperature or UV light variation. When the test specimens do not completely fill the racks, fill the empty spaces with blank non-rusting panels to maintain the test conditions within the chamber.

6.2 Use the test conditions specified by mutual consent or required by a product quality specification. Some test conditions in current use for testing paint and related coatings and materials are:

A = 8 h UV/70°C followed by 4 h CON/50°C for automotive coatings,
B = 4 h UV/60°C followed by 4 h CON/50°C for general metal coatings,
C = 4 h UV/60°C followed by 20 h CON/60°C for exterior wood coatings,
D = 8 h UV/60°C followed by 4 h CON/45°C for industrial maintenance coatings,
E = other test temperatures and time cycles that conform to the Procedure section of Practice G 53.

where:
UV = ultraviolet light (lamps) only, and
CON = condensation conditions only.

NOTE 1—Temperatures are black panel temperatures measured in the panel rack.

6.3 Program the selected test conditions and operate the apparatus continuously within the limits specified in Practice G 53. Service the apparatus in accordance with Practice G 53.

NOTE 2—Variations in results can occur as the result of not changing lamps in accordance with the manufacturer's instructions.

7. Periods of Exposure

7.1 Use one of the following methods to determine the duration of the exposure under this practice:

7.1.1 A mutually agreed upon specified number of total hours.

7.1.2 The number of total hours of exposure required to produce a mutually agreed upon amount of change in either the test specimen or an agreed upon standard sample.

8. Evaluation of Results

8.1 Evaluate conditions of exposed test specimens by means of one or more of the following standards: D 523, D 610, D 659, D 660, D 661, D 662, D 714, D 772, D 1654, D 1729, D 2244, D 2616, D 4214 and E 97. Select methods in accordance with product use requirements.

8.2 Because of possible variations in results as described in 3.4, no reference should be made to results obtained from tests conducted in the apparatus using this practice unless accompanied by Section 9 or unless otherwise specified in a reference procedure.

9. Report

9.1 Report the following information:

9.1.1 Manufacturer and model of fluorescent UV/condensation apparatus.

9.1.2 Manufacturer's designation for the fluorescent UV lamp and the relative spectral energy distribution of the lamp. This may be accomplished by listing the manufacturer's designation, wavelength (nm) where peak emission occurs, and the wavelength near low cut-off where 1 % of peak emission occurs.

9.1.3 Exposure cycle, for example, 4 h UV/60°C, 4 h CON/50°C.

9.1.4 Total exposure time.

9.1.5 Results of panel evaluation (see 8.1).

9.1.6 Identification of standard used for comparative evaluation, if any.

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[6] Apparatus and lamps from Q-Panel Co., 26200 First St., Cleveland, OH 44145 and from Atlas Electric Devices Co., 4114 N. Ravenswood Ave., Chicago, IL 60613, have been found suitable for this purpose.

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