Analysis of erythemal UVB dose received by drivers in Valencia, Spain

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ABSTRACT

Background/purpose

Continuous exposures to ultraviolet radiation can lead into harmful effects on human skin. Professional drivers may spend more than 8 hours per day inside a vehicle. UVER (erythemal ultraviolet radiation) received by driver and passenger inside a vehicle is analyzed.

Methods

For the study, a Peugeot 206, 3 doors, was used. Blue Line spores dosimeters of VioSpor were used for measurement of erythematic dose of UV radiation (able to produce erythema in human skin.) The response profile of these devices is extremely similar to human skin. Four dosimeters were placed on driver position and another four on passenger position. Also daily irradiance has been analyzed for a day in April using PMA radiometers. Measurements were obtained in relatively clear days from February to December 2009 between 9:30 h and 15:30 h. Additionally a prediction of time that should produce an erythema on driver skin has been obtained.

Results

There are some positions on driver position where UVER exposure exceeds Exposure Limits given by the International Radiation Protection Association (ICNIRP)

Conclusion

Health policies regarding skin protection should be taken into account for professional drivers in order to prevent them from harmful effects of UVER radiation on their skin.

Key words: UVER, erythema, irradiance.

INTRODUCTION

Nowadays there are many people who live in environments where there is a significant obstruction of the direct component of solar radiation due to the presence of buildings, vegetation and vehicles. Different studies have been focused on the influence of vegetables as barriers against UV radiation (1) and also building or constructive elements have also been analyzed (2). Many workers, like farmers or construction workers are influenced in their daily job by these elements and so, it is important for them to know how solar UVB radiation affects to their skin.

People spending their workday inside a vehicle, mainly a taxi or a bus, are a particular case. It is true that windows from a vehicle are formed by laminated sheet which can modify the transmitted spectrum (3) being a barrier against part of the solar UV radiation, mainly in the shorter wavelengths of the ultraviolet spectrum. However accumulated radiation exposure over an extended period of time, should be considered (4-8). In fact, it is found that, if the exposure is long enough, it can cause the appearance of erythema despite the presence of vehicle window. (3).

Bus and taxi drivers may spend more than 8 hours per day inside the bus or the taxi (9), therefore UVB radiation received should be taken into account.

The International Radiation Protection Association (ICNIRP) recommends a maximum personal exposure of 30 Jm^{-2} effective UV dose per 8-h period (10-13), which differs from the International Commission on Illumination (CIE) action spectrum (14), to which the spectral sensitivity of the spore film dosimeter used in our study corresponds. The relationship between CIE and ICNIRP weighted exposures depends on the time of day, changing position of the sun, ozone concentrations, etc. Gies and Wright (15) researched how

CIE and occupational weighted exposures can vary by factors of 3.5-4.5 at mid latitudes under different conditions. The relation applied here between the two action spectra as shown in Moehrle et.al (16) is: effective exposure CIE = 3.63 x effective exposure ACGIH, so that the effective ACGIH exposure (30 Jm^{-2}) is equal to an effective CIE exposure of 109 Jm^{-2} per workshift.

The goal of this paper is to analyze the differences between the overall erythemal UVB radiation (UVER) received under the full sun and UVER diffuse radiation received inside a vehicle in both cases: with windows opened and closed. Measurements have been made through a year, comparing the results in different seasons.

Also daily irradiance in $\mu W/cm^{-2}$ during a day of April.

Furthermore an analysis of time spent until erythema has been included, showing, for each position of a person inside a car, and each skin Type (17) the time needed to produce an erythema on skin. This information may be really important in order to develop health policies for drivers.

MATERIALS AND METHODS

Measurements were carried out at the Institute of Electrical Technology located in the Technological Park of Paterna (Valencia) (39 ° 32 '46.72 "N, 0 °, 27' 12" W).

Vehicle description: A Peugeot 206 4-1360 cc., 1.4 l. 2000, 3 doors, was used for the study. Its dimensions are: 3.82 meters of length, 1.67 meters of wide and 1.44 meters height.

The type of glass for the side windows, windshield and rear window is tempered.

Measurements of erythematic dose received: Measurements were made on relatively clear days from February to December 2009 from 9:30h to about 15:30h (local time).

In Table 1, a list of measurement days and atmospheric conditions is shown. The average daily temperature, average relative humidity, average wind speed and average global solar radiation were measured by the weather station of CEAM (19):

<Table 1>

where the value of θ, zenith angle, is the sunlight incidence average angle on an horizontal surface in a day between 9h and 15 hours.

A UV-sensitive spore-film filter system (VioSpor Blue Line Type II Dosimeter; Bio-Sense, Bornheim, Germany) was used as the UV dosimeter. Spore-film production (DNA repair-deficient strain of Bacilus subtilis) and the development of the films are described elsewhere. The spore films are covered by a filter system with optical properties simulating the erythematic response of human skin in accordance with the CIE reference spectrum.

Situation of dosimeters for measuring the UVER: For measurements inside the vehicle, 8 dosimeters were used: 4 for driver and 4 for passenger. The positions selected were: horizontal over the driver's head, 17 cm away from car's roof (HD), vertical toward the driver's window, 24 cm away from driver's window (LD), vertical towards the windshield, 85 cm away from windshield and 35 cm away from driver's window (VD), horizontal on the driver's armrest (AD), horizontal over the passenger's head, 17 cm away from car's roof (HP), vertical toward the driver's window, 88 cm away from driver's window (LP), vertical toward the windshield, 85 cm away from windshield and 100 cm away from driver's window (VP) and horizontal on the passenger's armrests (AP). The distance between driver's and passengers' seat was of 18 cm.

Additionally, two dosimeters were placed outside the car in order to compare the results taken inside and outside the car. Conditions inside a vehicle are difficult to simulate in a standardized way (17). Therefore measures were obtained with the car in a stationary

position and oriented so that the driver's window was always perpendicular to the sun rays any time.

Every 45 minutes the car was turned approximately 10° in order to accomplish the condition mentioned above.

Measurement of erythemal daily UVER irradiance with radiometers: Measurements were made on April 22th and 24^{th,} 2009 from 9:30h to about 15:30 (local time). Only driver position has been analyzed, placing one sensor horizontally and one sensor in vertical position pointing towards the window.

Two PMA2100 sensors have been employed: one placed horizontally and the other one vertically. The PMA 2102 UVB radiometer was calibrated by comparison, under solar radiation, with a reference detector, the UVB-1. In a UVB-1 radiometer (Yankee Environment System-YES), the calibration uncertainty is approximately 10%.

Situation of radiometers for measuring daily irradiance: Sensors have been place one in horizontal and the other one in vertical position, as mentioned above. Both place in driver's seat, and the vertical one pointing towards the window. Windows have been closed and opened alternatively each one hour in order to compare both conditions.

Time to erythema: In order to evaluate the time that would produce an erythema on skin driver (or passenger), a simple relationship between exposure limit of UVER dose to erythema for each skin type, given by CIE, and dose received over a period of time measured inside a car, has been used.

RESULTS

Erythematic dose

The measurements were divided into four periods: a) February-March, b) May-June, c) July-September,d)October-November-December.

Averaged values of incidence angle of sunlight rays on a horizontal surface have been calculated for these four seasonal periods of time.

Comparison with Exposure Limits: In the following tables, erythematic dose received on dosimeters, with vehicle windows opened and closed and for both positions, driver and passenger, and in full sun, are shown.

<Table 2>

<Table 3>

<Table 4>

<Table 5>

Taking a look at results shown in tables 2 to 5, it can be concluded that vehicle windows can be considered as effective barriers against UVER dose received. In fact, for any time of the year, UVER dose values with closed windows are lower than Exposure Limit for driver and passenger with the only exception of driver's arm in July-September period (135.5 J/m^2).

In the case of opened windows, the dose received for driver and passenger can be higher than Exposure Limit value, reaching values in July-September period for drivers that are higher in a factor of 3.1 in the case of lateral position, and of 3.6 in the case of arm position.

Exposure ratio (ER): Different Exposure ratios are studied:

$UVER_{CW}$ / $UVER_A$ defined as the UVER radiation dose received with car windows closed in J/m^2 / UVER radiation dose received in full sun in J/m^2.

$UVER_{OW}$ / $UVER_A$ defined as the UVER radiation dose received with car windows opened in J/m² / UVER radiation dose received in full sun in J/m².

<Chart 1>

<Chart 2>

Taking a look at Tables 4 to 7 combined with Charts 1 and 2, it can be observed that the most dangerous positions for driver, regarding to the UVER received, are vertical toward the driver's window (LD) and horizontal on the driver's armrest (AD), in both cases: opened and closed windows.

For LD position, values of $UVER_{OW}$ / $UVER_A$ range from 48% to 115%, whereas for closed windows, the ratio $UVER_{CW}$ / $UVER_A$ range from 30% to 51%.

For AD position values of $UVER_{OW}$ / $UVER_A$ range from 61% to 97%, whereas for closed windows, the ratio $UVER_{CW}$ / $UVER_A$ range from 19% to 29%.

Analyzing the ratio $UVER_{OW}$ / $UVER_A$ it is shown that, for months in which averaged zenith angle is high (February-March and October-November-December), the value of the ratio for LD position is higher in 58.3% with respect to months in which averaged zenith angle is low (May-June and July-September).

There are some positions inside the car which are less dependent on the positions of windows: HD and VD.

Charts 3 and 4 show the values of the different Exposure ratios (ER) for each period, on passenger position.

<Chart 3>

<Chart 4>

It is important to remark the fact that, on passenger position, there is less influence of solar radiation coming from window because it is affected by many shadows and reflections coming from everywhere inside the vehicle, including the driver which is very close.

However, taking a look at charts 3 and 4, it is observed that positions of passenger where dose can be higher are LP, AP and also VP, in both cases opened and closed windows.

With respect to exposure ratios, we can observe many differences between passenger and driver's case. In particular, for AP and AD position, ratio of $UVER_{OW}$ / $UVER_A$ is 20.7% lower in the case of passenger in October-November-December, reaching a value 84.2% lower for February-March period. Also in $UVER_{CW}$ / $UVER_A$ differences are observed. In this case, the ratio is shown to be 7.3% lower in the case of passenger for May-June period, reaching a value of 80.4% lower in February-March-April period.

For LD and LP positions, the difference between driver and passenger is clearly shown in $UVER_{OW}$ / $UVER_A$ ratio. In this case the ratio reaches a value 94.8 lower in the case of passenger for February-March-April period.

Daily Irradiance: Despite the fact that, with closed windows, the daily irradiance received for both, vertical and horizontal positions is almost negligible, with a maximum value of 0.098 $\mu W/cm^2$ corresponding to vertical position at 12:30h, it can be observed that, for opened windows the values may reach an important percentage of incident radiation, with a maximum of 6.94 $\mu W/cm^2$ at 11:34h. In this case of opened windows, it can be observed that in vertical position daily irradiance is higher than in horizontal position.

This difference may be of a 98% in the case of 11:15h and has a slowly decrease while reaching the midday, with a value of 79.1% at 13:10h.

Time to erythema

In general, time to erythema use to be high for a person inside a vehicle, there are positions where erythema on skin may appear in less than one hour (LD in February-March-April). However it should happen with opened windows, which is not the general case in winter.

In AD position in May-June, an erythema would appear in only 40 minutes if windows would be opened.

For passenger, time to erythema is even higher than for driver. However, there also some particular case in which erythema may appear in 45 minutes (AP in may-june with windows opened).

DISCUSSION

Erythematic dose received and daily irradiance inside a vehicle, in the case of opened and closed windows, has been compared for driver and passenger positions and during a year.

It can be seen that higher differences between UVER dose received by driver and passenger are given in months when the solar zenith angle is greater. This is because when the Sun reaches a higher zenith angle, it arrives more perpendicularly inside the vehicle. For that reason the driver's position, are most directly affected by the radiation received that the passenger who is also favored by the effect of shadow due to the physical presence of driver.

However, for months when the solar zenith angle is lower, both driver and passenger position, are benefited by the action of roof vehicle that serves as a physical barrier against radiation. That is true because the vehicle has been placed in such a way that driver’s window is always oriented to sun. If sun would be coming from passenger’s window, probably the result woud have been completely opposite to those shown in this study.

For future research should be interesting to study dose UVER received inside a vehicle during a real travel. In that case sun would be changing its relative position alternatively over driver and passenger positions.

Also daily Irradiance has been analyzed by two radiometers placed inside a vehicle, just on driver position, one horizontally and the other one in vertically pointing to window. As it was hoped from the study of UVER dose, vertical position receives a higher amount of Irradiance compared with the horizontal position, and the difference is higher early in the morning more than at midday. The reason is that at first light in the morning, solar zenith angle has a higher value and therefore sun falls on vertical radiometer more perpendicularly. At midday, the obstruction due to vehicle roof decreases the difference between vertical and horizontal position.

Finally Time to erythema has been analyzed in order to show a clear guide to non-expert people in order to know how much time would spend until erythema will appear. Same conclusions as mentioned before can be taken from these table.

Entering into the table with position, time of the year and skin phototype, everybody can estimate the time that will pass until erythema.

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CHART CAPTIONS

Chart 1: Ratio $UVER_{CW}$ / $UVER_{A}$ for driver throughout the year.

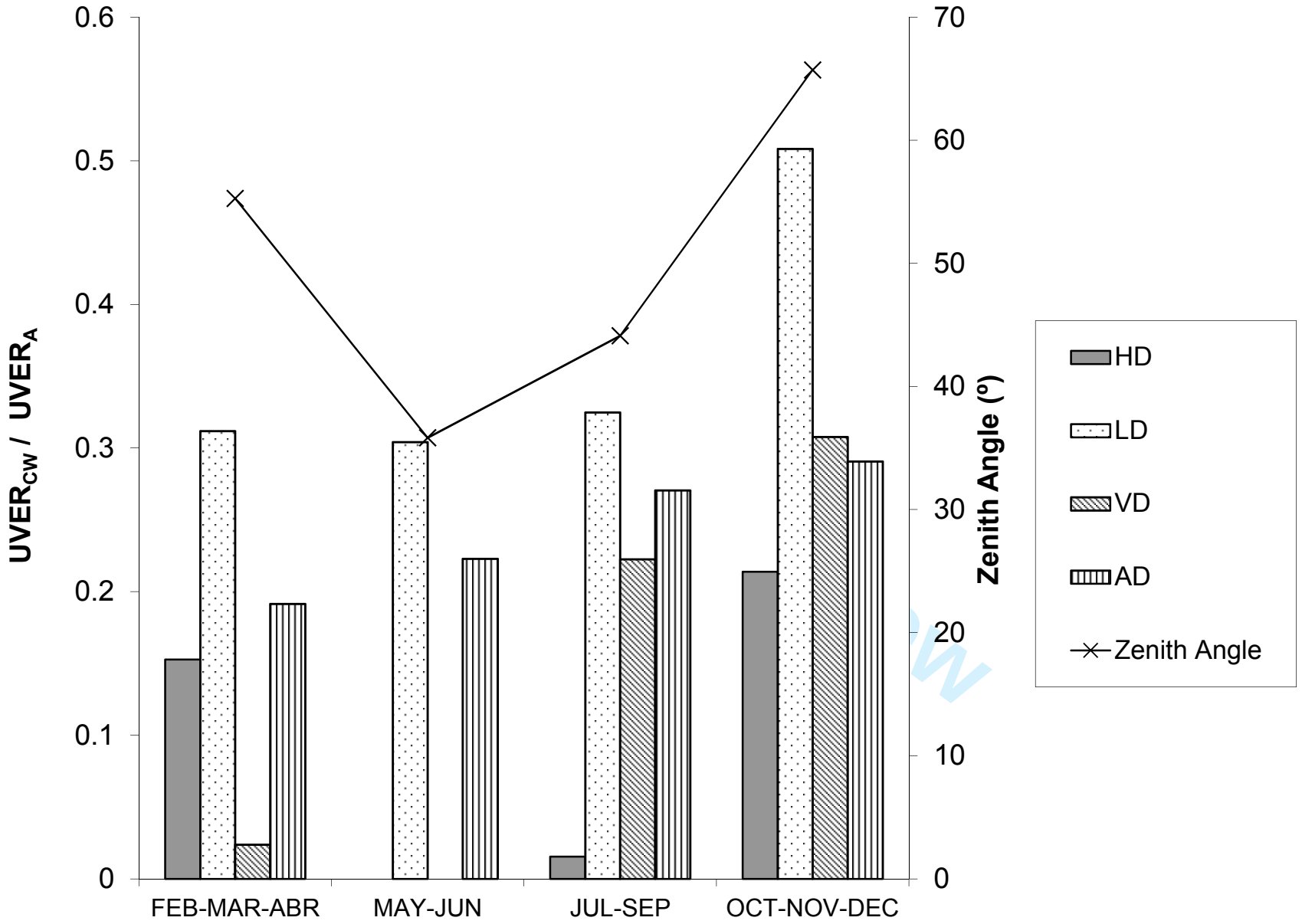
Chart 2: Ratio $UVER_{OW}$ / $UVER_{A}$ for driver throughout the year.

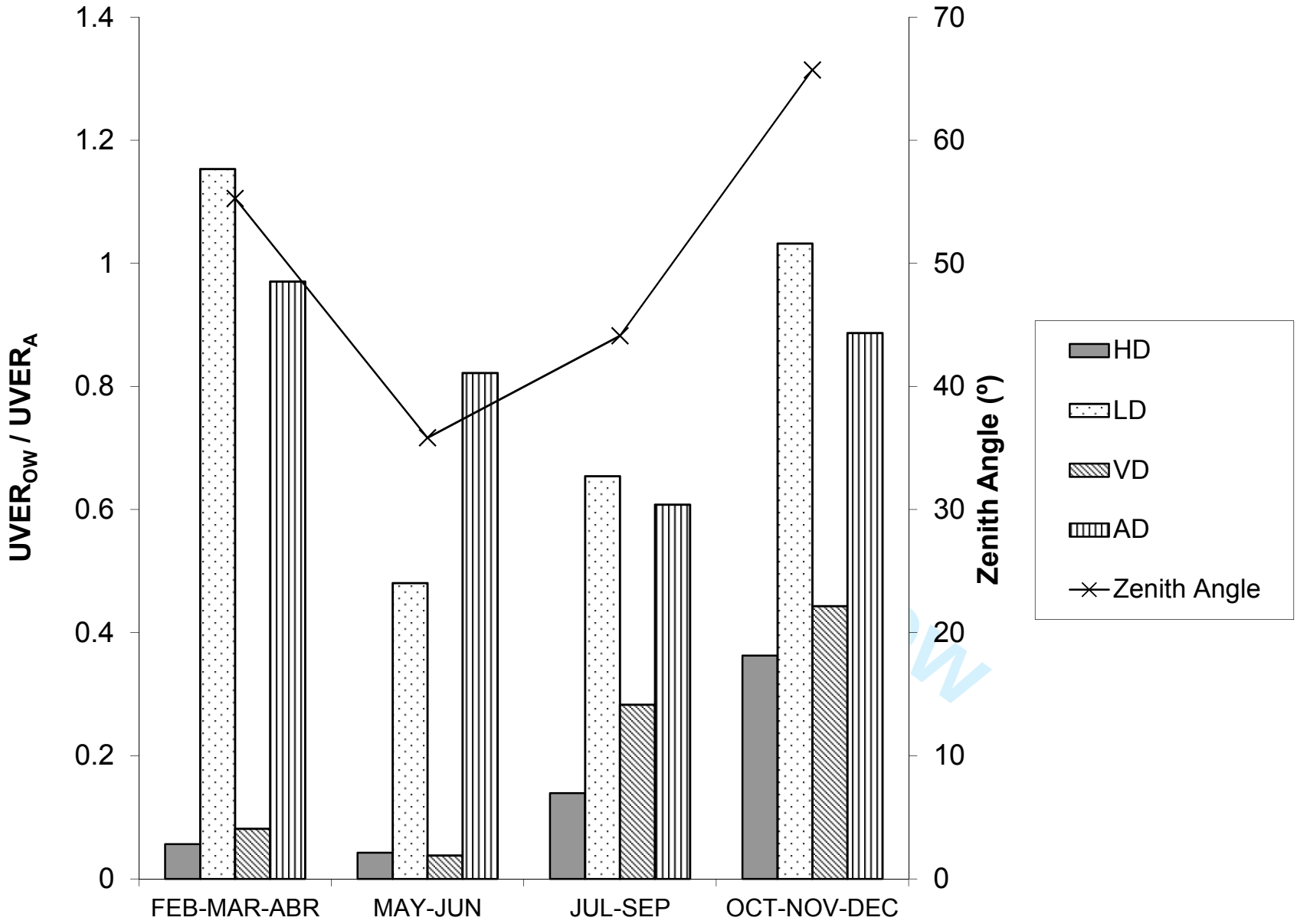
Chart 3: Ratio $UVER_{CW}$ / $UVER_{A}$ for passenger throughout the year.

Chart 4: Ratio $UVER_{OW}$ / $UVER_{A}$ for passenger throughout the year.

Chart 5: UVER Daily Irradiance for a day in April with opened windows.

Chart 6: UVER Daily Irradiance for a day in April with closed windows.


0.6
0.5
0.4
0.3
0.2
0.1
0
70
60
50
40
30
20
10
0
UVER$_{CW}$ / UVER$_A$
Zenith Angle (º)
FEB-MAR-ABR
MAY-JUN
JUL-SEP
OCT-NOV-DEC
HD
LD
VD
AD
Zenith Angle


1.4
1.2
1
0.8
0.6
0.4
0.2
0
70
60
50
40
30
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10
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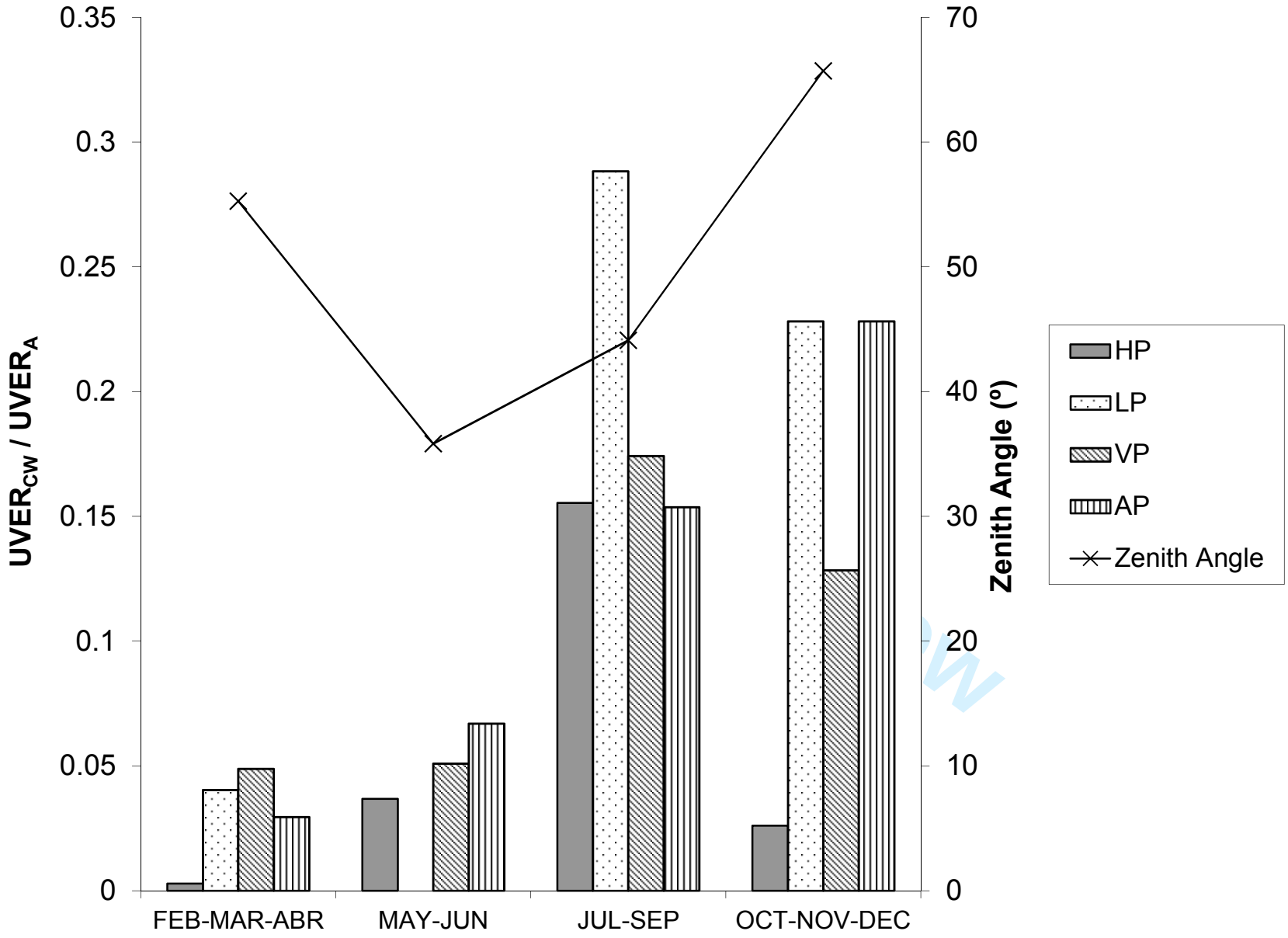
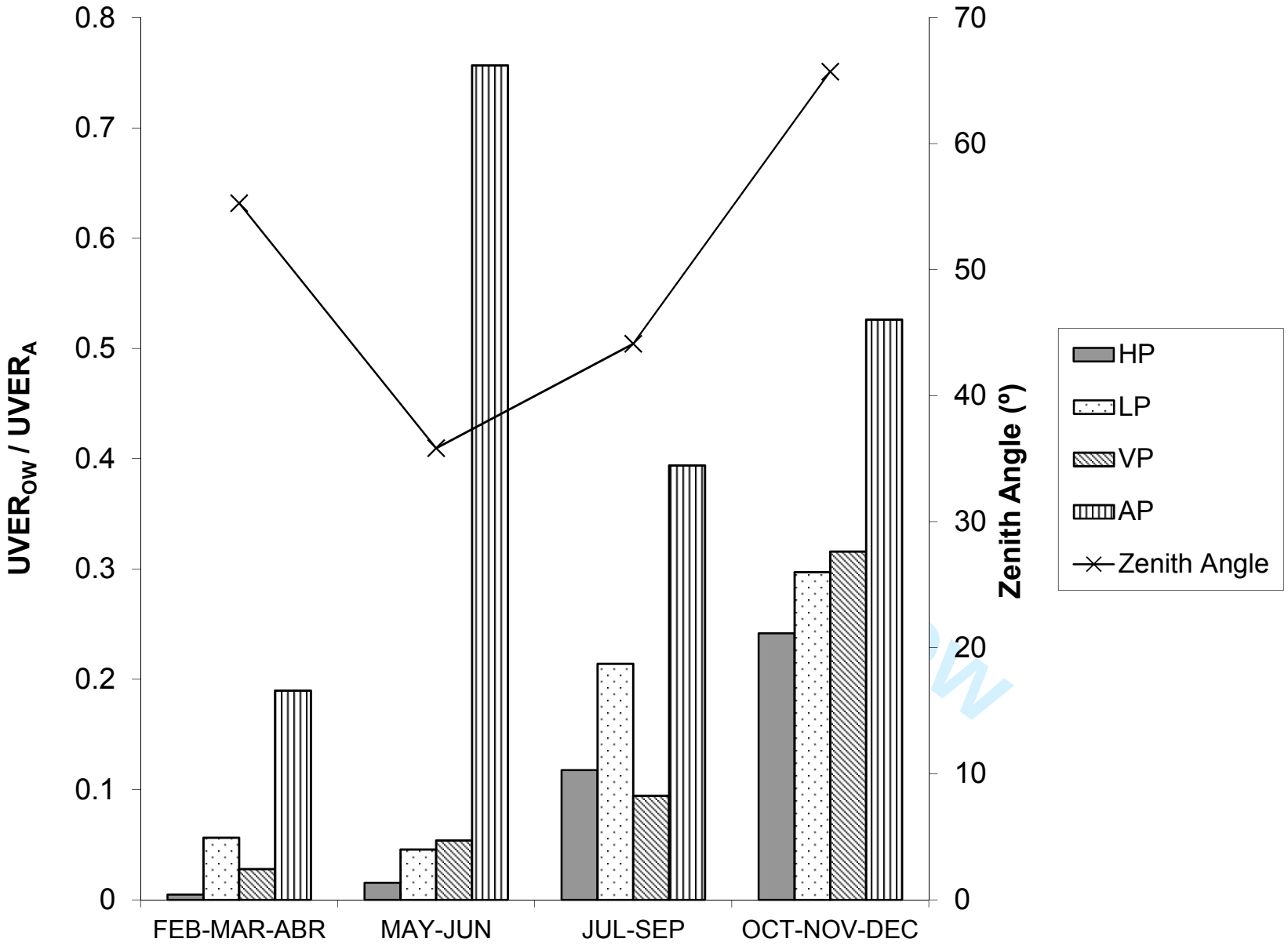
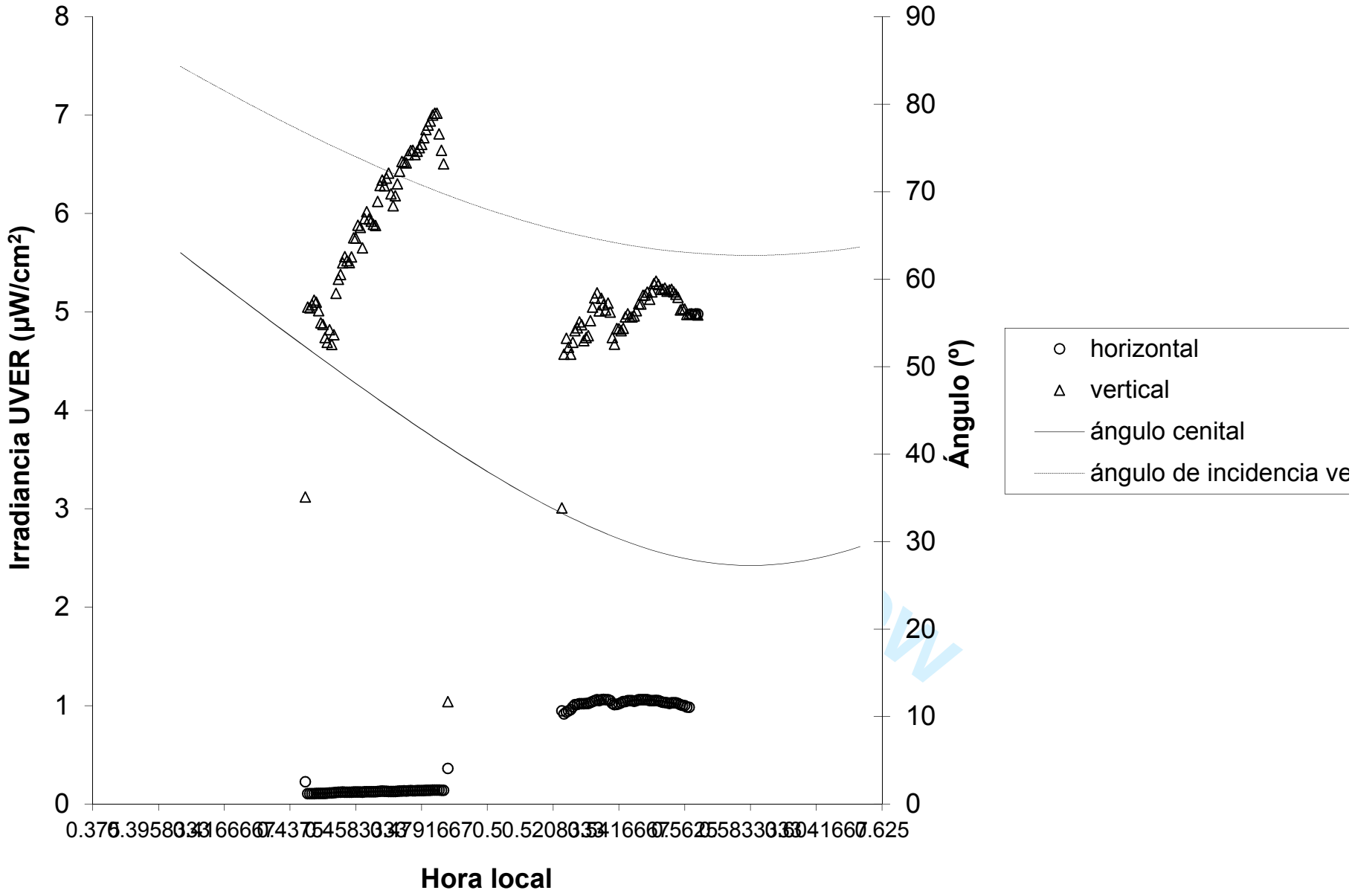
UVER$_{OW}$ / UVER$_{A}$
Zenith Angle (º)
FEB-MAR-ABR
MAY-JUN
JUL-SEP
OCT-NOV-DEC
HD
LD
VD
AD
Zenith Angle


0.35
0.3
0.25
0.2
0.15
0.1
0.05
0
70
60
50
40
30
20
10
0
UVER$_{CW}$ / UVER$_A$
Zenith Angle (°)
FEB-MAR-ABR
MAY-JUN
JUL-SEP
OCT-NOV-DEC
HP
LP
VP
AP
Zenith Angle


0.8
0.7
0.6
0.5
0.4
0.3
0.2
0.1
0
70
60
50
40
30
20
10
0
UVER_OW / UVER_A
Zenith Angle (º)
FEB-MAR-ABR
MAY-JUN
JUL-SEP
OCT-NOV-DEC
HP
LP
VP
AP
Zenith Angle


Irradiancia UVER (µW/cm²)
Ángulo (°)
Hora local
horizontal
vertical
ángulo cenital
ángulo de incidencia ve
0
1
2
3
4
5
6
7
8
0
10
20
30
40
50
60
70
80
90
0.375
0.625

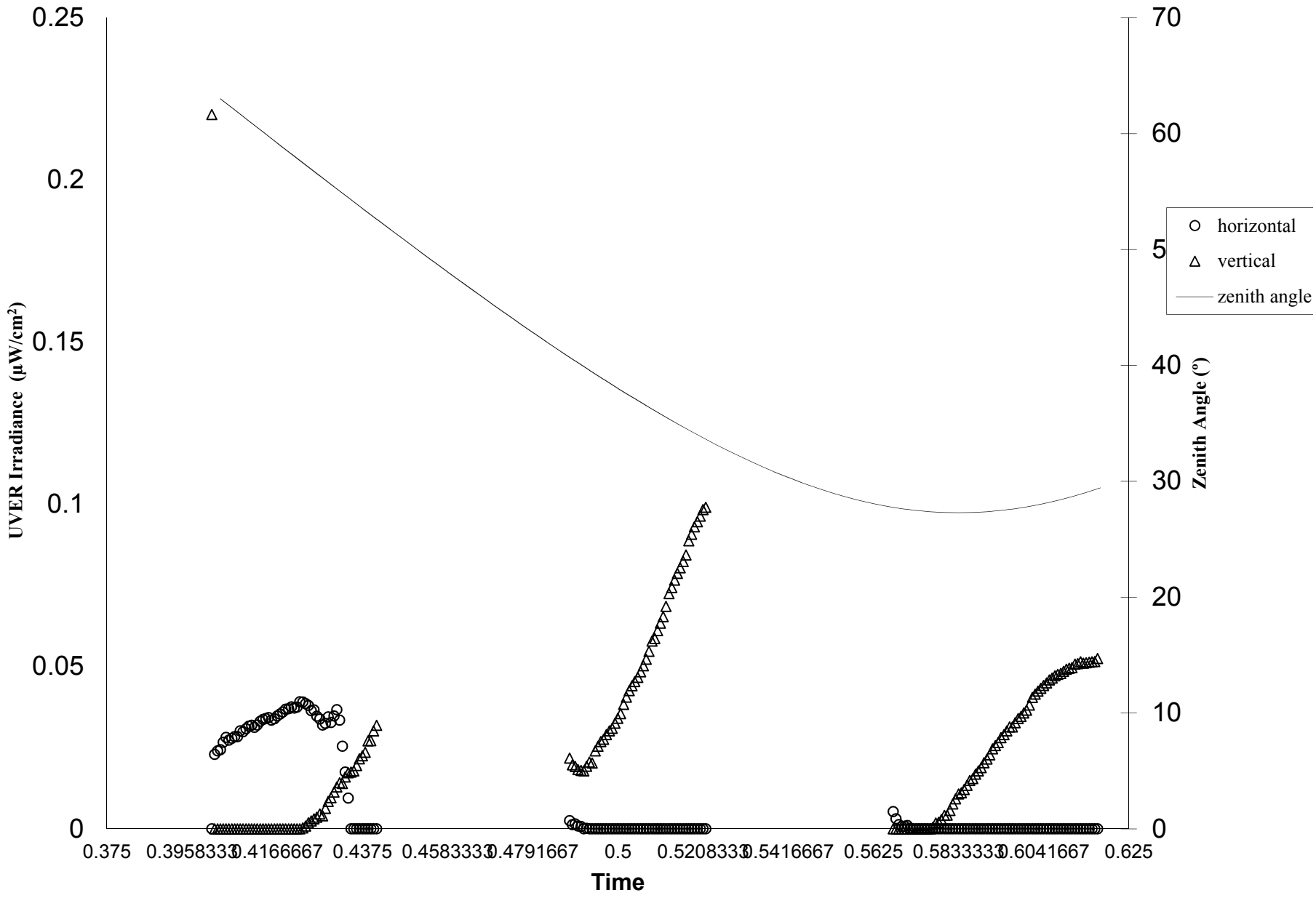

0.25
0.2
0.15
0.1
0.05
0
UVER Irradiance (µW/cm²)
70
60
50
40
30
20
10
0
Zenith Angle (°)
horizontal
vertical
zenith angle
0.375
0.3958333
0.4166667
0.4375
0.4583333
0.4791667
0.5
0.5208333
0.5416667
0.5625
0.5833333
0.6041667
0.625
Time

Table 1: Measurement days for UVER dose (climate data provided by CEAM).

Date (d/m/y)	Air temperature (°C)	Relative Humidity (%)	Wind Speed (m/s)	Global radiation (W/m²)	Ozone (D.U.)	θ (°)
23-26-27/02/2009	13.7	58.2	2	510.1	342	60
5-6-9-10-13-24/03/2009	16	42.3	4.8	608.6	342.2	54.6
22-24/04/2009	21.5	39.5	3.1	798.6	337	41.3
4-26-28/05/2009	24.3	34.2	2.9	797.4	342.3	35.8
1-22-29/06/2009	25.3	57.6	3.1	757.4	324	33.3
2-17-24-29/07/2009	30.1	50	3.3	739	301	35
16-21-22-25/09/2009	23	47.4	2.7	561	318.8	51.6
1-6-21-22-30/10/2009	21.2	53.8	4.8	512.7	292.7	58.7
2-9-10/11/2009	18.1	36.4	3.63	399.13	279	66.2
1-9/12/2009	13.1	45.3	4.21	342.4	270	71

Table 2: UVER dose received inside a vehicle for the different positions studied in February-March

Dosimeter position	UVER dose with closed windows (J/m^2)	UVER dose with opened windows (J/m^2)	UVER dose under the sun (J/m^2)
HD	24.7	9.1	161.8
LD	53.4	197.4	
VD	4.1	14	171.2
AD	31	157.1	
HP	0.5	0.8	
LP	6.9	9.7	
VP	8.4	4.8	
AP	4.8	30.7	

Table 3: UVER dose received inside a vehicle for the different positions studied in May-June period.

Dosimeter position	UVER dose with closed windows (J/m^2)	UVER dose with opened windows (J/m^2)	UVER dose under the sun (J/m^2)
HD	0	16.8	394.2
LD	69.3	183.8	
VD	0	14.5	227.7
AD	87.9	324	
HP	14.5	6.1	
LP	0	17.4	
VP	11.6	20.6	
AP	26.4	298.4	

Table 4: UVER dose received inside a vehicle for the different positions studied in July-September period.

Dosimeter position	UVER dose with closed windows (J/m^2)	UVER dose with opened windows (J/m^2)	UVER dose under the sun (J/m^2)
HD	7.5	90.2	488.7
LD	103.6	333.5	
VD	71	144.3	319
AD	135.5	393.6	
HP	76	76	
LP	92	109.1	
VP	55.6	48.1	
AP	75.1	254.9	

Table 5: UVER dose received inside a vehicle for the different positions studied in October-November-December period.

Dosimeter position	UVER dose with closed windows (J/m^2)	UVER dose with opened windows (J/m^2)	UVER dose under the sun (J/m^2)
HD	36.8	40.5	133
LD	88.8	120.2	
VD	53.8	51.6	135.2
AD	50	99	
HP	4.5	27	
LP	39.9	34.6	
VP	22.4	36.7	
AP	39.3	58.8	

Table 6: Time to erythema depending on position and time of the year.

Dosimeter position	February-March-April		May-June		July-August-September		October-November-December	
	CW	OW	CW	OW	CW	OW	CW	OW
Skin Type I								
HD	7h 23min	20h 29min	∞	12h 54min	38h27min	3h13min	5h29min	3h51min
LD	3h 25min	56min	3h 2min	1h 10min	2h48min	52min	2h16min	1h18min
VD	44h 40min	13h 20min	∞	14h 55min	4h5min	2h0min	3h45min	3h2min
AD	5h 54min	1h 11min	2h 24min	40min	2h11min	44min	4h2min	1h35min
HP	393h 12min	251h	14h 30min	35h 32min	3h49min	3h49min	45h5min	5h47min
LP	26h 23min	19h 18min	∞	12h 25min	3h9min	2h39min	5h4min	4h31min
VP	21h 50min	38h 59min	18h 8min	10h 32min	5h13min	6h1min	8h60min	4h15min
AP	38h 10min	6h 4min	7h 58min	43min	3h51min	1h8min	5h9min	2h39min
Skin Type II								
HD	9h 14min	25h 36min	∞	16h 8min	48h4min	4h1min	6h52min	4h49min
LD	4h 16min	1h 10min	3h 48min	1h 28min	3h30min	1h5min	2h50min	1h37min
VD	55h 51min	16h 40min	∞	18h 39min	5h6min	2h31min	4h41min	3h47min
AD	7h 22min	1h 28min	3h	50min	2h44min	55min	5h3min	1h58min
HP	491h 30min	313h 45min	18h 7min	44h 25min	4h46min	4h46min	56h21min	7h14min
LP	32h 59min	24h 7min	∞	15h 32min	3h56min	3h19min	6h20min	5h39min
VP	27h 18min	48h 44min	22h 40min	13h 10min	6h31min	7h31min	11h15min	5h19min
AP	47h 43min	7h 35min	9h 58min	54min	4h49min	1h25min	6h26min	3h19min
Skin Type III								
HD	12h 55min	35h 51min	∞	22h 36min	67h17min	5h37min	9h36min	6h45min
LD	5h 59min	1h 39min	5h 19min	2h 3min	4h54min	1h31min	3h59min	2h16min
VD	78h 11min	23h 21min	∞	26h 7min	7h9min	3h31min	6h34min	5h18min
AD	10h 19min	2h 4min	4h 11min	1h 10min	3h50min	1h17min	7h4min	2h46min
HP	688h 6min	439h 15min	25h 22min	62h 11min	6h40min	6h40min	78h54min	10h8min
LP	46h 10min	33h 47min	∞	21h 45min	5h31min	4h39min	8h52min	7h54min
VP	38h 13min	68h 13min	31h 44min	18h 27min	9h7min	10h32min	15h45min	7h26min
AP	66h 48min	10h 37min	13h 57min	1h 16min	6h45min	1h59min	9h0min	4h39min

Dosimeter position	February-March-April		May-June		July-August-September		October-November-December	
	CW	OW	CW	OW	CW	OW	CW	OW
Skin Type IV								
HD	16h 37min	46h 6min	∞	29h 3min	86h30min	7h14min	12h21min	8h40min
LD	7h 42min	2h 7min	6h 50min	2h 39min	6h18min	1h57min	5h7min	2h55min
VD	100h 31min	30h 1min	∞	33h 35min	9h11min	4h31min	8h27min	6h49min
AD	13h 15min	2h 40min	5h 23min	1h 30min	4h56min	1h39min	9h5min	3h33min
HP	884h 42min	564h 45min	32h 37min	79h 57min	8h35min	8h34min	101h26min	13h1min
LP	59h 22min	43h 26min	∞	27h 58min	7h5min	5h58min	11h23min	10h9min
VP	49h 9min	87h 43min	40h 48min	23h 43min	11h44min	13h32min	20h14min	9h34min
AP	85h 53min	13h 40min	17h 56min	1h 38min	8h40min	2h33min	11h34min	5h59min
Skin Type V								
HD	20h 19min	56h 21min	∞	35h 30min	105h44min	8h50min	15h6min	10h36min
LD	9h 24min	2h 36min	8h 21min	3h 14min	7h41min	2h23min	6h15min	3h34min
VD	122h 52min	36h 41min	∞	41h 3min	11h13min	5h31min	10h19min	8h19min
AD	16h 12min	3h 16min	6h 35min	1h 50min	6h1min	2h1min	11h6min	4h20min
HP	1081h 18min	690h 15min	39h 52min	97h 43min	10h29min	10h29min	123h59min	15h55min
LP	72h 34min	53h 6min	∞	34h 11min	8h40min	7h18min	13h55min	12h25min
VP	60h 4min	107h 13min	49h 52min	28h 59min	14h20min	16h33min	24h44min	11h41min
AP	104h 58min	16h 42min	21h 55min	2h	10h36min	3h8min	14h9min	7h18min
Skin Type VI								
HD	24h 1min	66h 35min	∞	41h 58min	124h57min	10h26min	17h51min	12h32min
LD	11h 7min	3h 4min	9h 52min	3h 49min	9h5min	2h49min	7h23min	4h13min
VD	145h 13min	43h 21min	∞	48h 31min	13h16min	6h31min	12h12min	9h50min
AD	19h 9min	3h 51min	7h 47min	2h 10min	7h7min	2h24min	13h7min	5h8min
HP	1277h 54min	815h 45min	47h 7min	115h 30min	12h23min	12h23min	146h31min	18h49min
LP	85h 46min	62h 45min	∞	40h 24min	10h14min	8h38min	16h27min	14h40min
VP	70h 59min	126h 43min	58h 57min	34h 15min	16h56min	19h33min	29h14min	13h48min
AP	124h 4min	19h 45min	25h 55min	2h 21min	12h32min	3h42min	16h43min	8h38min