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Vision Experiment on Perception of Correlated Color Temperature

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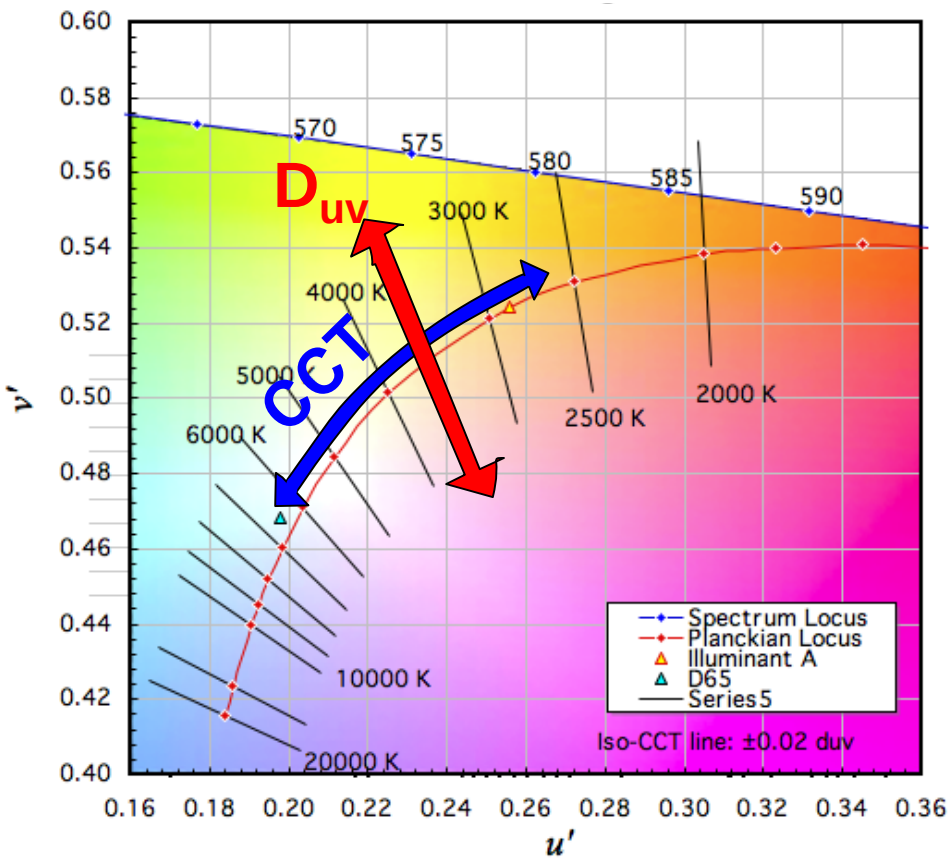
Chromaticity expression for lighting

CCT (Correlated Color Temperature)

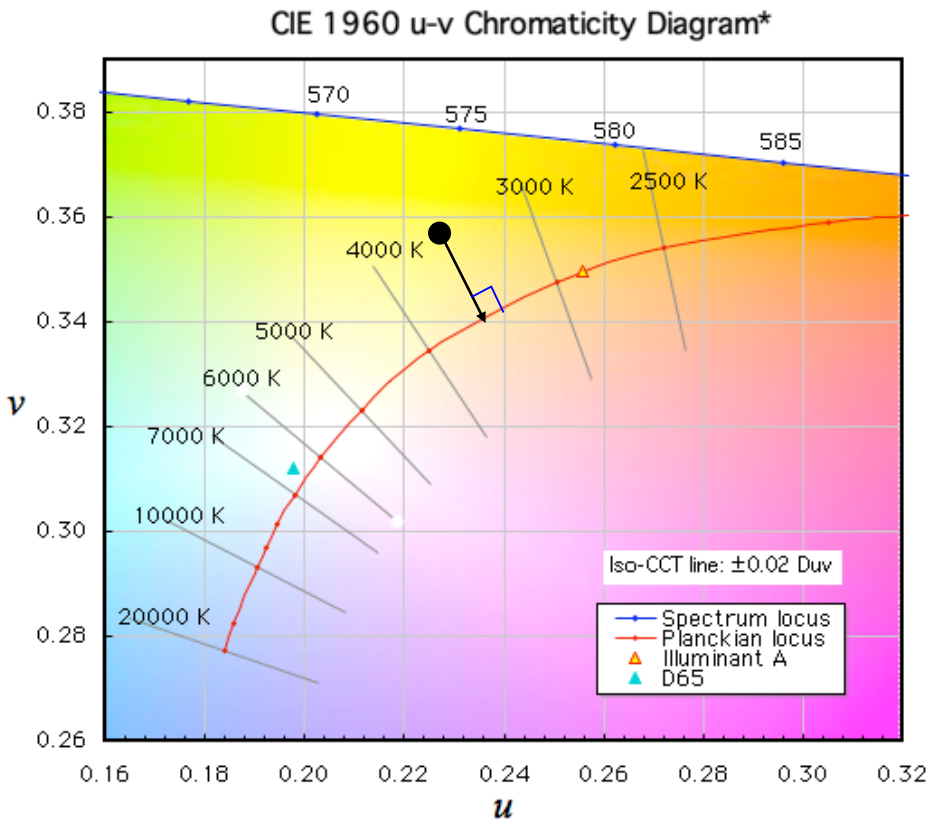
D_{uv} (Shift from Planckian locus)



The use of CCT and Duv is the intuitive way to express the chromaticity of light sources for lighting.

Correlated Color Temperature (CCT)

Temperature [K] of a Planckian radiator whose chromaticity is closest to that of a given stimulus on the CIE (*u', 2/3 v'*) coordinate.

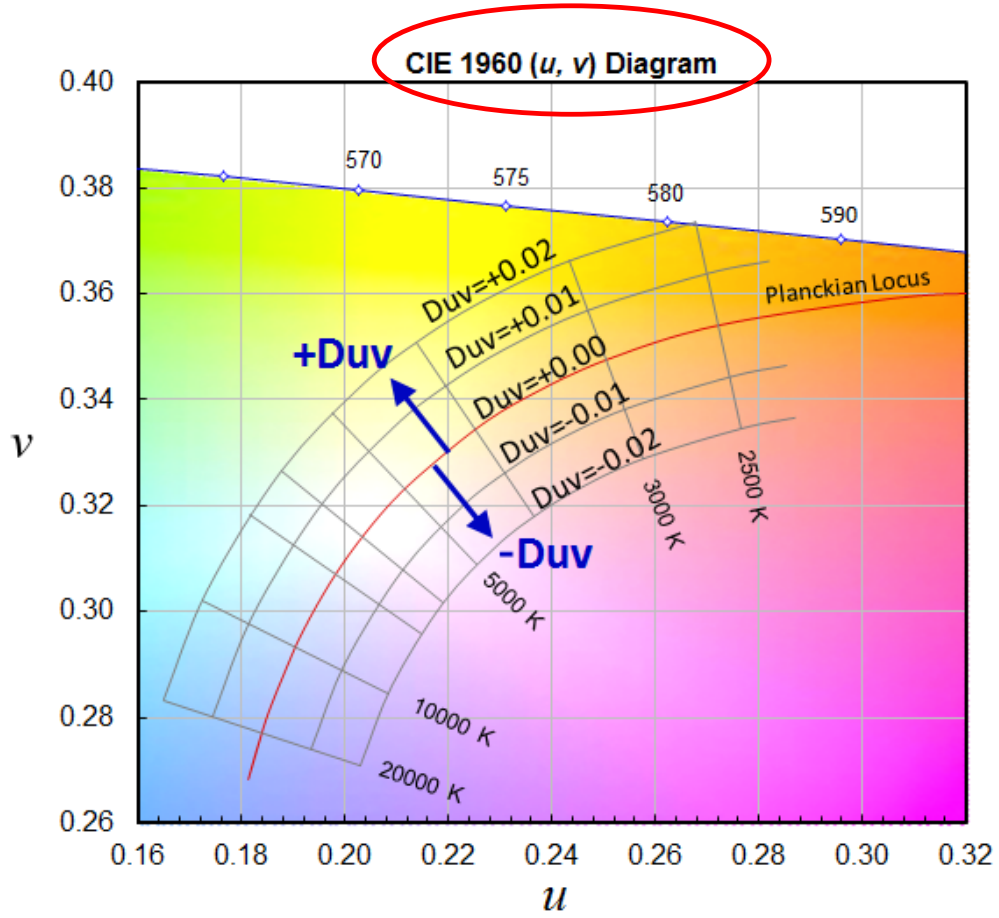


(CIE 15:2018, also in CIE ILV)

CIE (*u', 2/3 v'*) is the CIE 1960 (*u, v*) coordinate, which is now obsolete.

D_{uv} – Distance from Planckian Locus

Closest distance from the Planckian locus on the (u', 2/3 v') diagram, with + sign for above and - sign for below the Planckian locus.



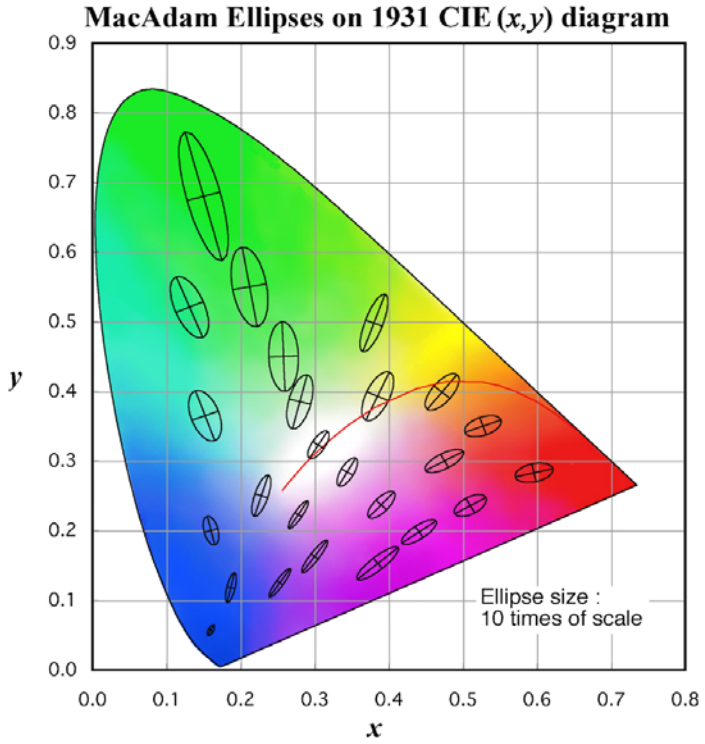
Defined first in ANSI C78.377-2008.

Now also in CIE 15:2018.

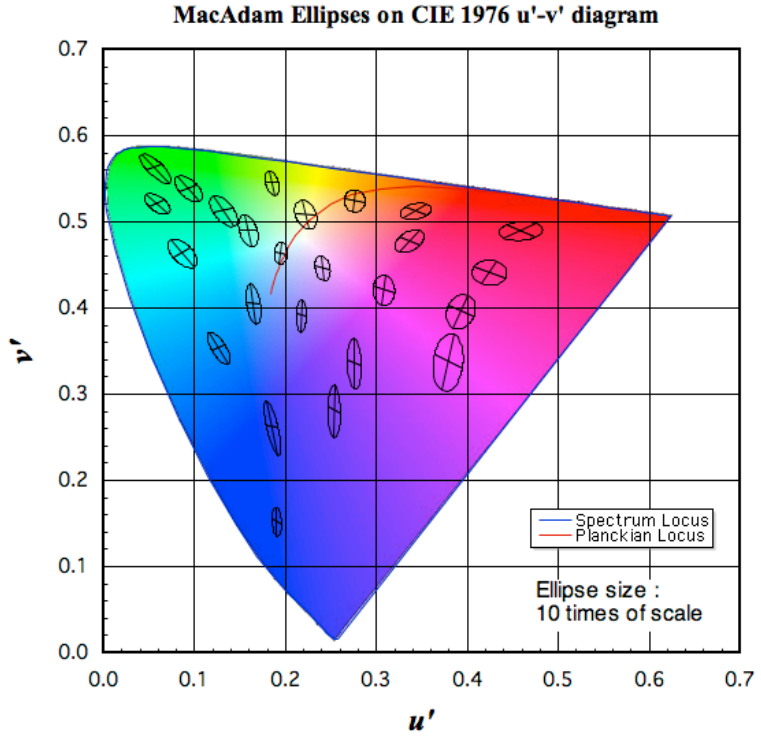
CIE 1960 (u, v) is obsolete

---- Officially Recommended Chromaticity Diagrams -----

CIE 1931 (x,y)

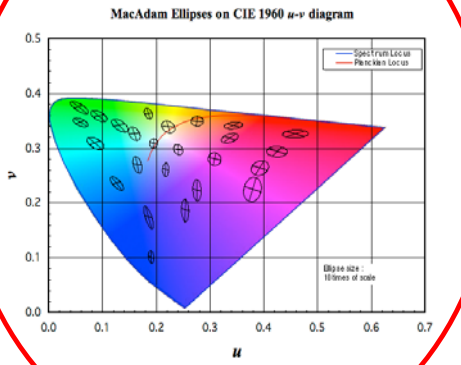


CIE 1976 (u',v')



CIE 1960 (u,v)

obsolete



cie
International Commission on Illumination
Commission Internationale de l'Eclairage
Internationale Beleuchtungskommission

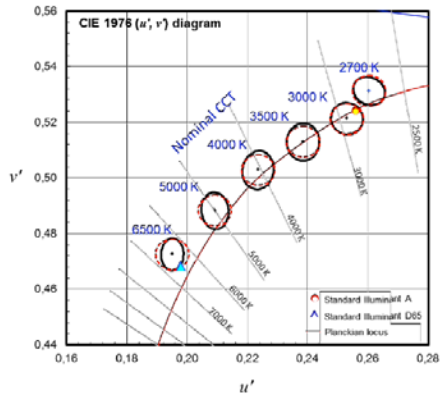
TECHNICAL NOTE

Chromaticity Difference Specification for Light Sources

CIE TN 001:2014

3.1 $u'v'$ Circle

Recommended for color difference (tolerance) specifications for lighting products – replacing MacAdam Ellipses



4 Chromaticity difference $\Delta_{u',v'}$

is expressed between two points (u'_1, v'_1) and (u'_2, v'_2) on the CIE (u',v') diagram by,

$$\Delta_{u',v'} = \sqrt{(u'_2 - u'_1)^2 + (v'_2 - v'_1)^2}$$

Discussion in CIE

$D_{uv,}$ based on (u,v), and $\Delta_{u'v',}$ based on (u',v'), are making confusions in the industry.

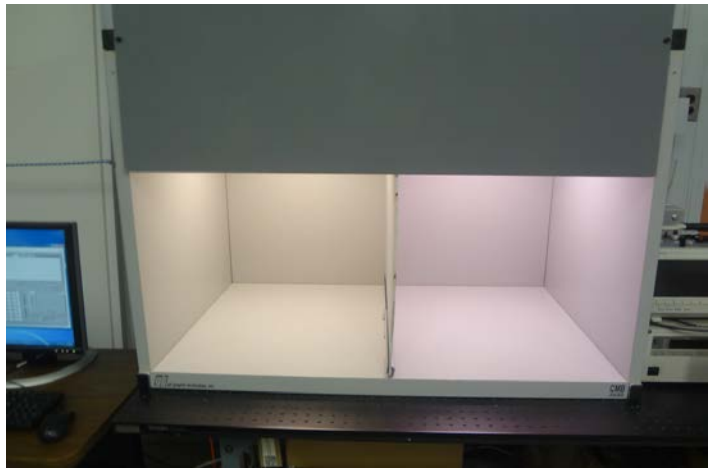
A need for changing the definition of CCT (and Duv) to (u',v'). Scientific data needed. Which diagram correlates better with perception of CCT?

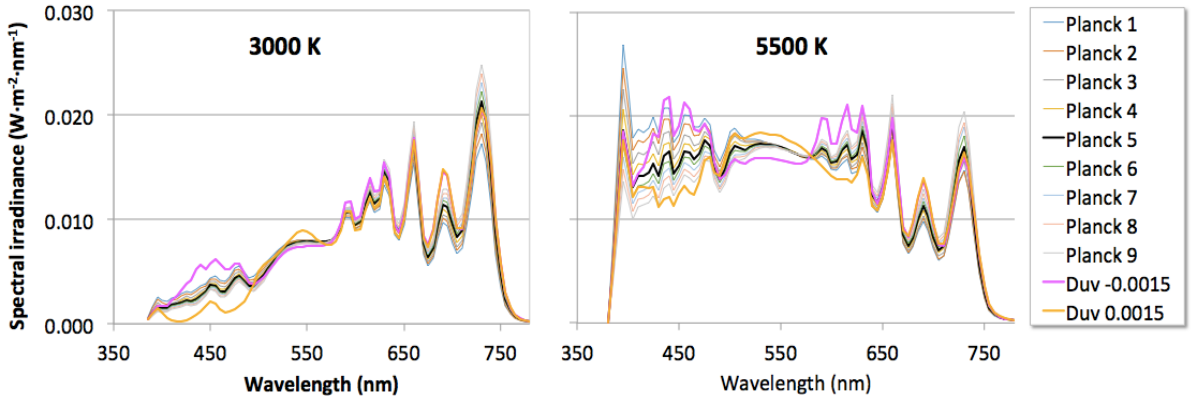
CIE Division 1 started a reportership in 2017:

DR 1-67	Revisiting Correlated Colour Temperature	Reporter: Dr. Youngshin Kwak

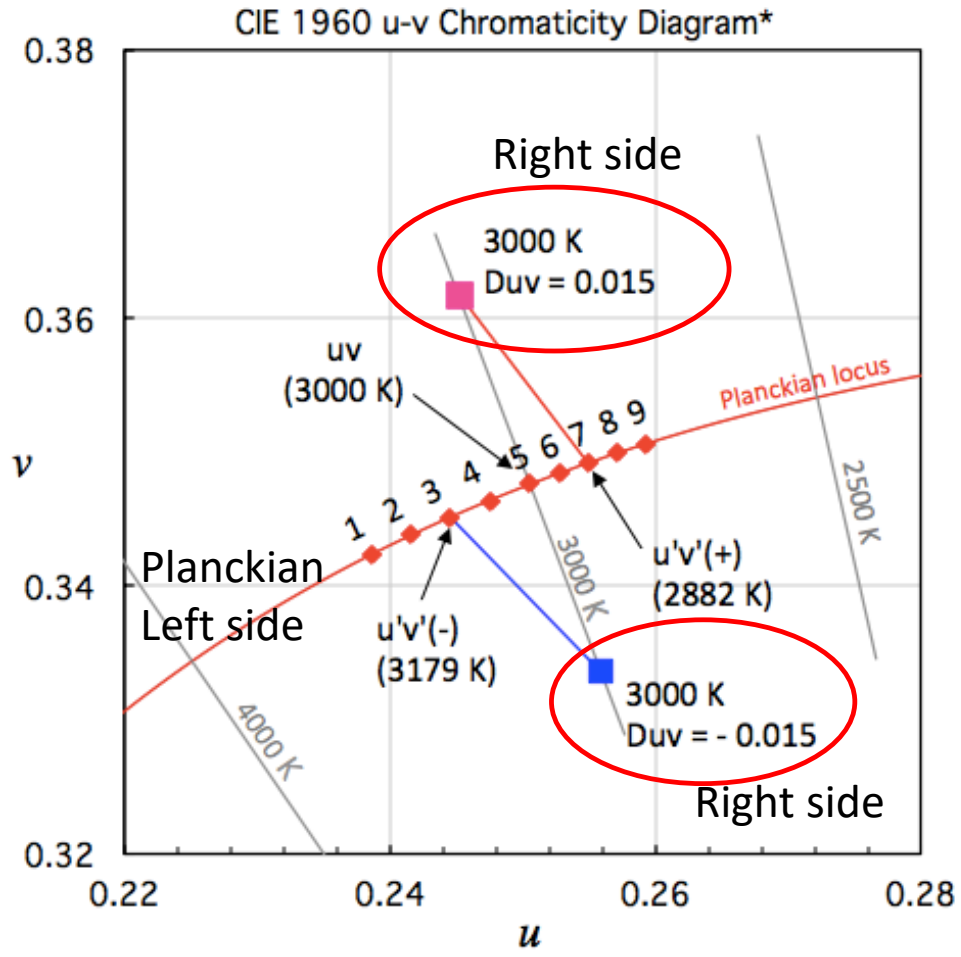
NIST 2016 Experiment

Experimental Facility (Spectrally tunable double-booth)

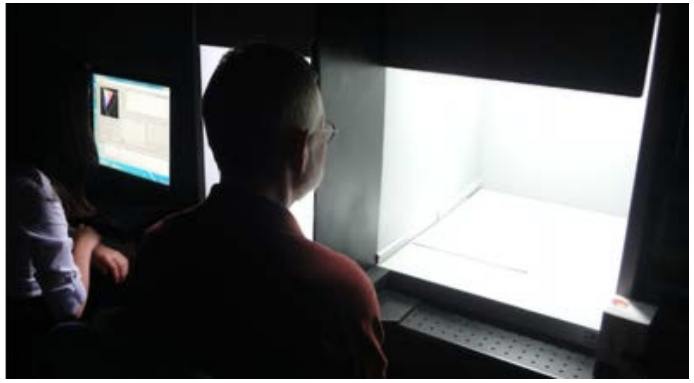




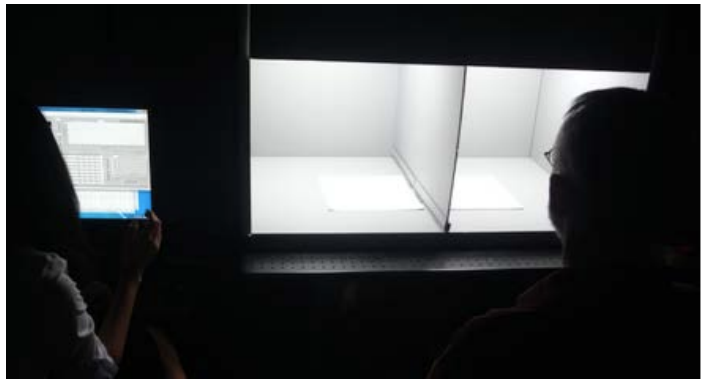
Experimental Method (2016)



Haploscopic



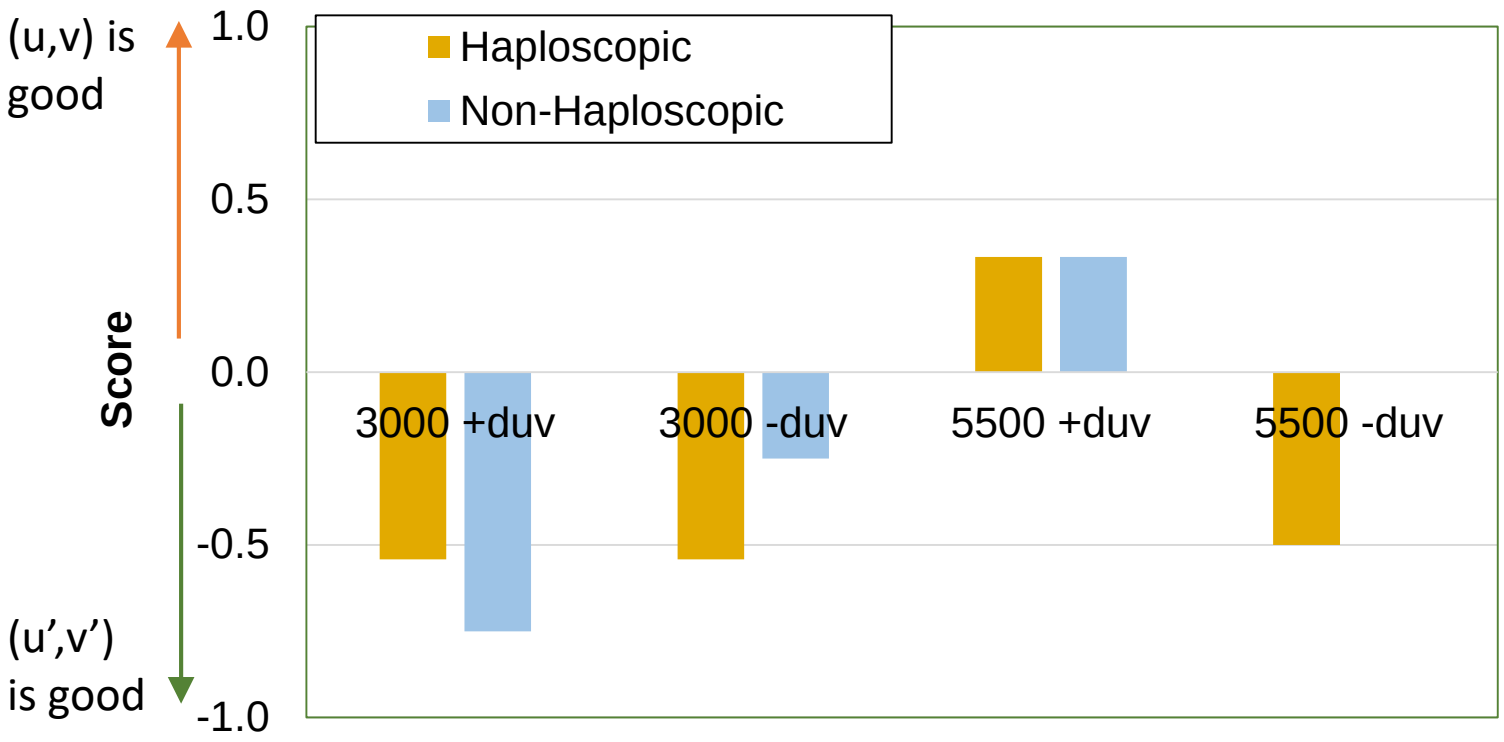
Non-haploscopic



12 subjects

- 8 males and 4 females
- 20 to 71 years old
- 7 white and 5 Asians.

Results of 2016 Experiment (Re-analyzed)



Kwak, Y., Ha, H., Ohno, Y., "Vision Experiments on Perception of Correlated Color Temperature," Proc., CIE 2017 Midterm conference, Jeju, Korea, CIE x044:2017, 512-521 (2017).

2019 Experiment at NIST

Purpose: To investigate the perception of CCT in conditions closer to real lighting applications.

Experimental Facility: NIST Spectrally Tunable Lighting Facility

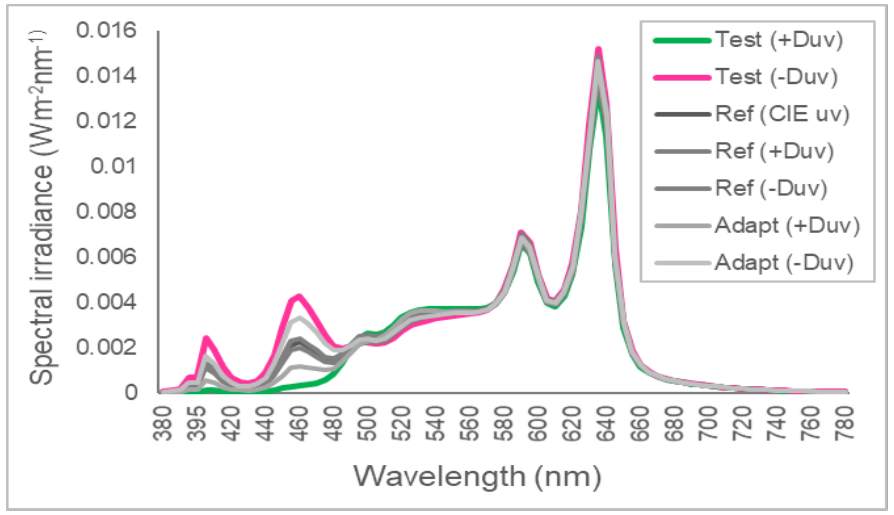
Subjects: Total 22
11 males, 11 females
Age: 18 to 64 years old

Illuminance: 300 lx (on the table)

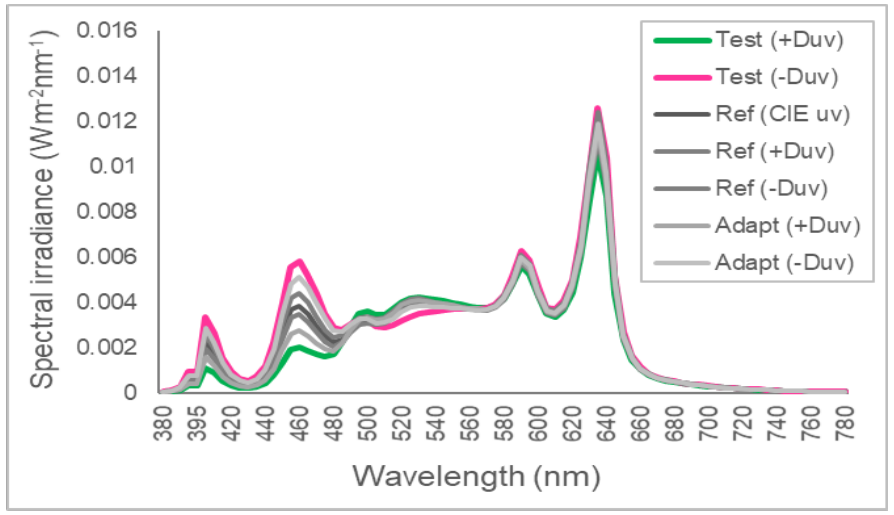
CCT: 2700 K, 3500 K, 4500 K, 6500 K

Evaluation:
View the entire room.

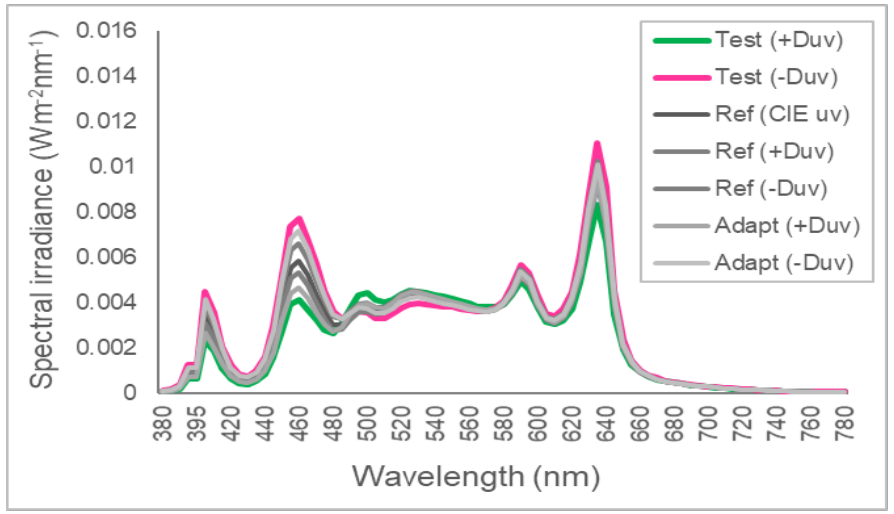
SPDs of the lights used



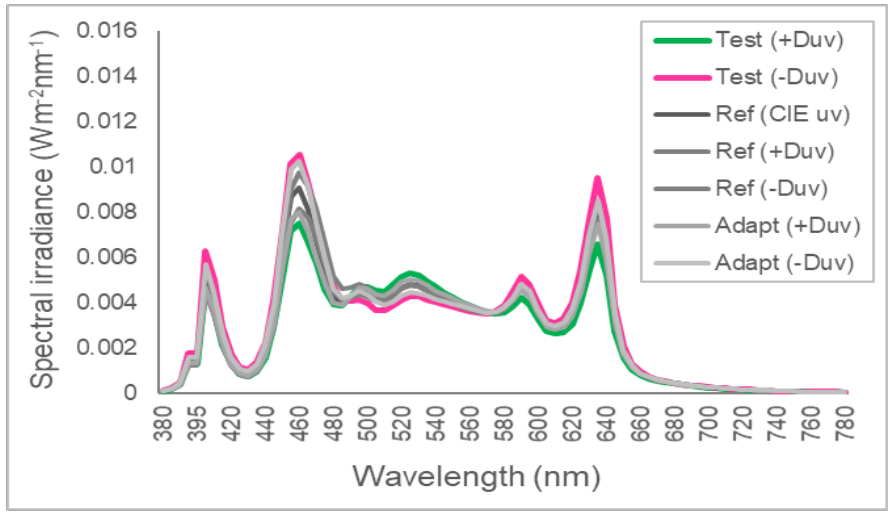
a) 2700K



b) 3500K

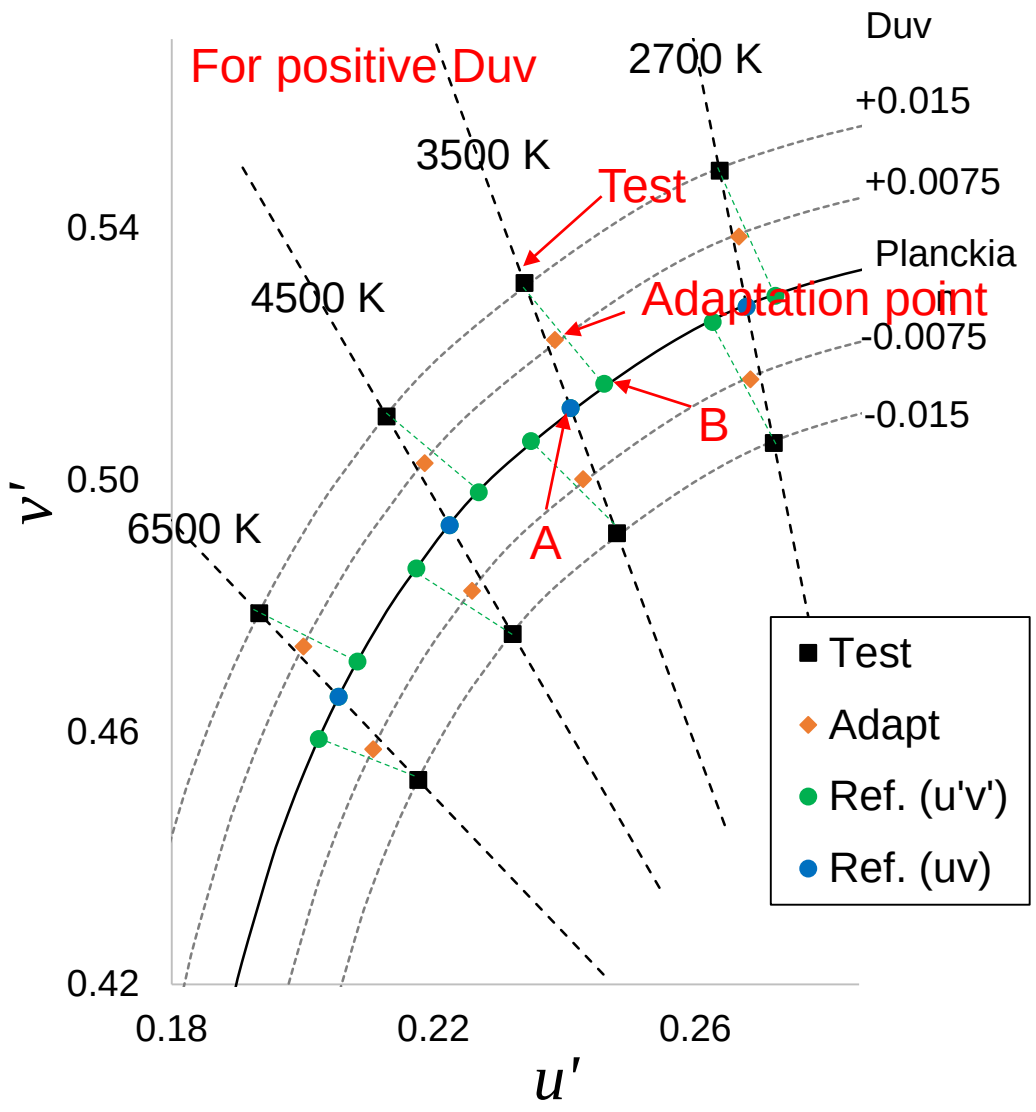


c) 4500K



d) 6500K

Method of Experiment



Procedures

Preparation

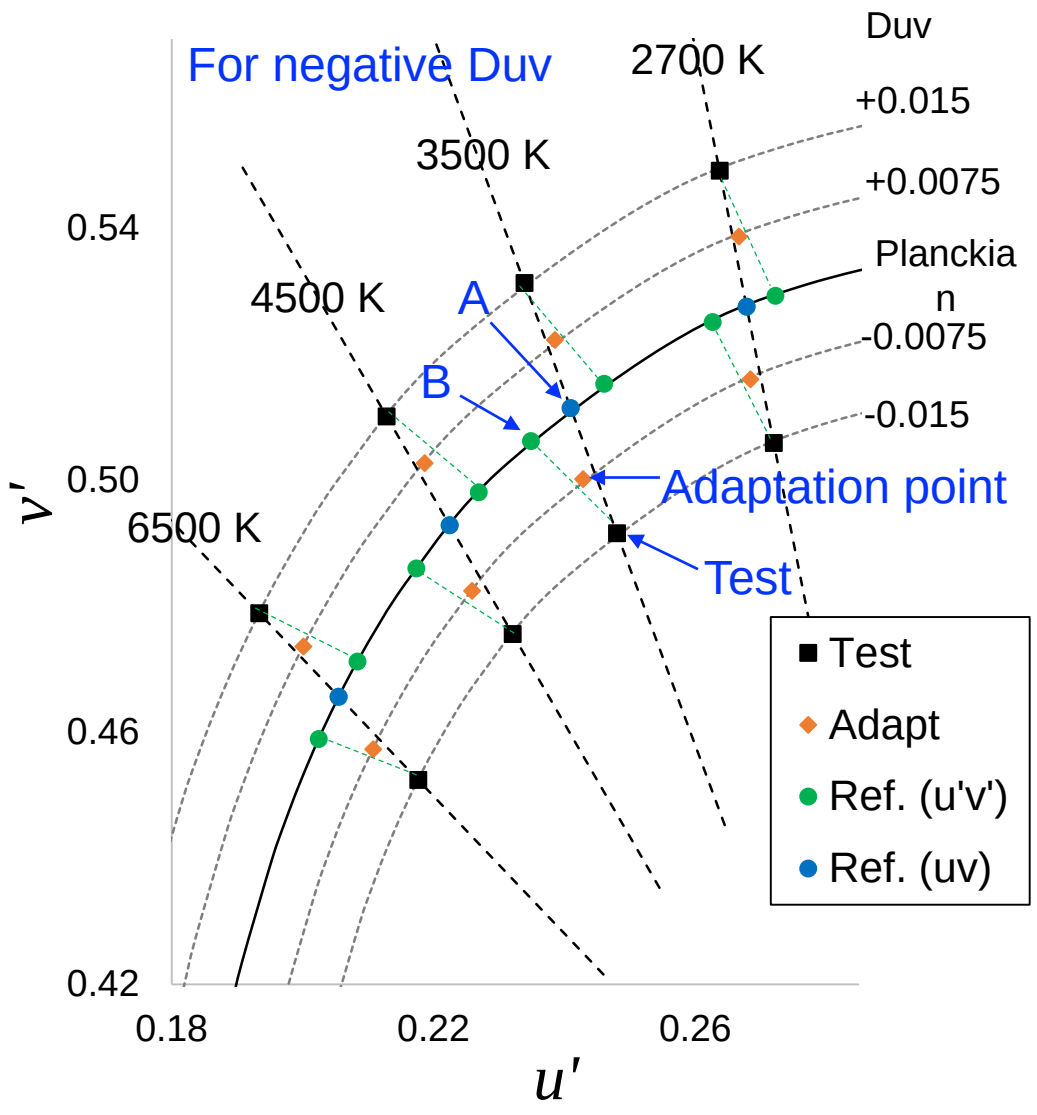
Ishihara test

Practice session

At each CCT:

1) Subject adapted to Adaptation point for 2 min.
2) Present:
   Test – A – B – Test
3) Repeat:
   Test – B – A – Test
   (Repeat as necessary)
4) Ask which of A or B is closer (color) to Test? Also, "difficult" if choice is difficult.

Method of Experiment



Procedures

Preparation
- Ishihara test
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Data Analysis

1) Raw data (A or B)

	CCT order		2-1-4-3	4-3-2-1	1-2-3-4	1-3-2-4	2-4-1-3	4-2-1-3	1-3-2-4	4-
	Duv order		m-p-m-p	m-p-p-m	m-p-m-p	p-p-p-m	m-p-p-m	p-m-m-m	p-m-m-p	m-
Sequence	CCT	Duv	Sub1	Sub2	Sub3	Sub4	Sub5	Sub6	Sub7	
1	2700	plus	BD	B	B	B	B	BD	B	
	2700	minus	B	B	A	B	B	BD	B	
2	3500	plus	A	A	A	B	A	A	B	
	3500	minus	BD	B	B	B	AD	A	BD	
3	4500	plus	AD	A	AD	A	A	A	B	
	4500	minus	A	B	B	AD	AD	A	A	
4	6500	plus	AD	A	A	B	A	A	B	
	6500	minus	AD	B	B	B	AD	AD	A	

* A = uv / B = u'v' / AD or BD means it was difficul

2) Converted score data (+1 or -1)

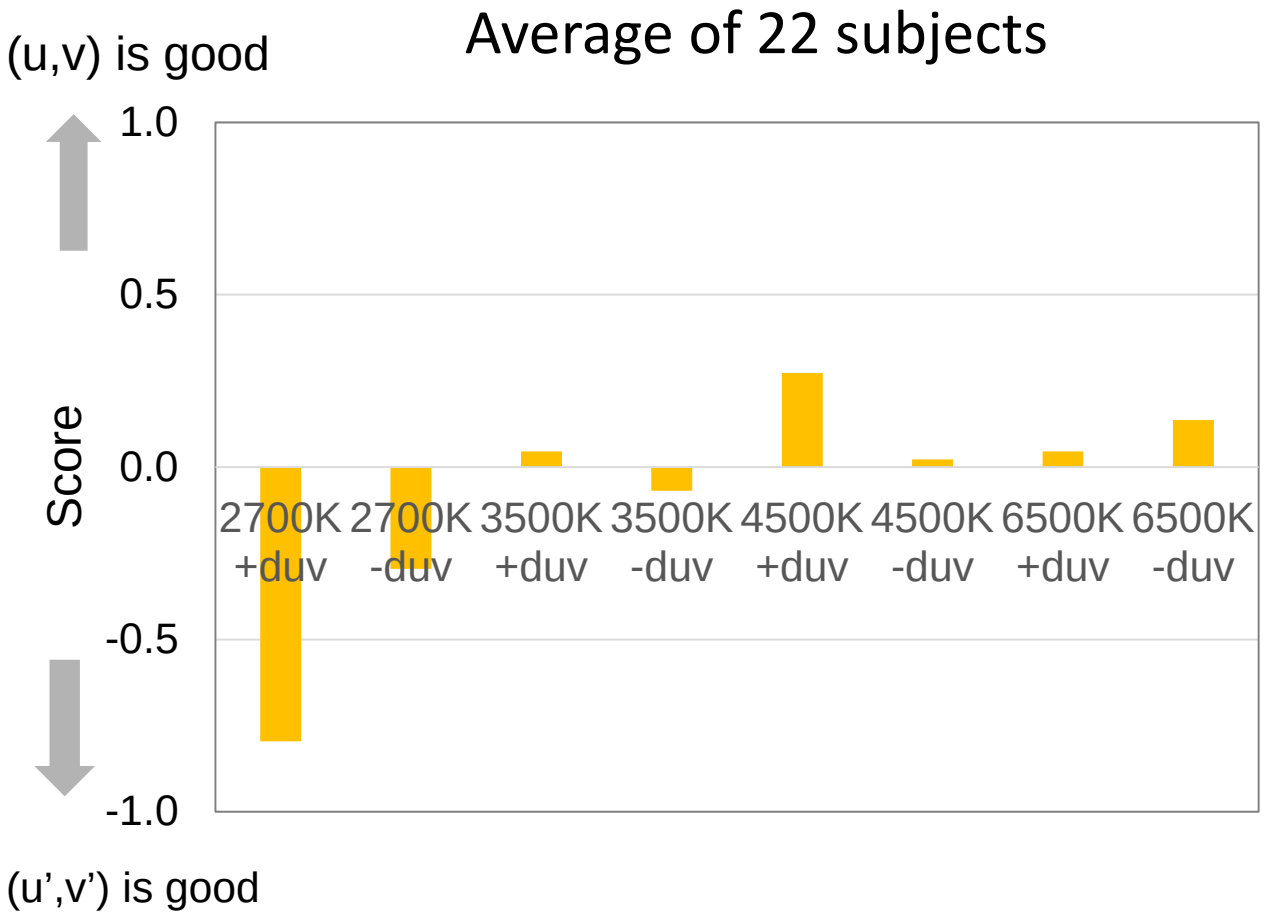
Sequence	CCT	Duv	Sub1	Sub2	Sub3	Sub4	Sub5	Sub6	Sub7
1	2700	plus	-0.5	-1	-1	-1	-1	-0.5	-1
	2700	minus	-1	-1	1	-1	-1	-0.5	-1
2	3500	plus	1	1	1	-1	1	1	-1
	3500	minus	-0.5	-1	-1	-1	0.5	1	-0.5
3	4500	plus	0.5	1	0.5	1	1	1	-1
	4500	minus	1	-1	-1	0.5	0.5	1	1
4	6500	plus	0.5	1	1	-1	1	1	-1
	6500	minus	0.5	-1	-1	-1	0.5	0.5	1

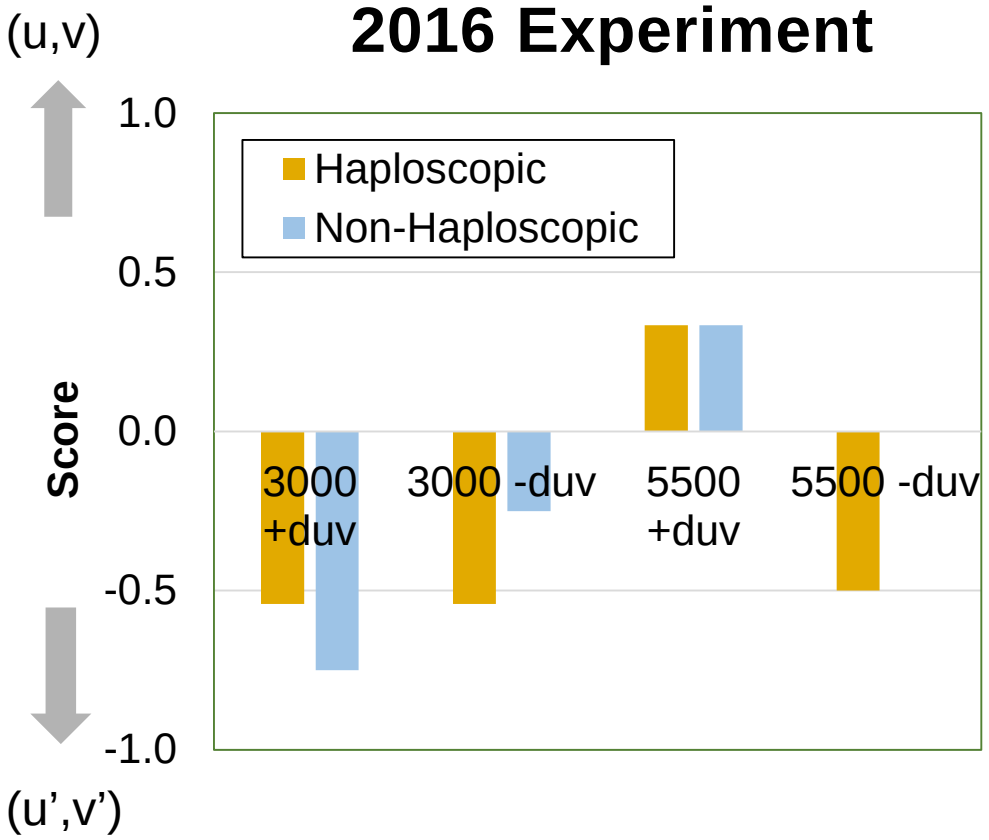
* A = 1 / B = -1

0.5 *Score allocation for Difficult responses

Sub22	Average
-1	-0.80
1	-0.30
1	0.05
1	-0.07
-1	0.27
1	0.02
-1	0.05
1	0.14

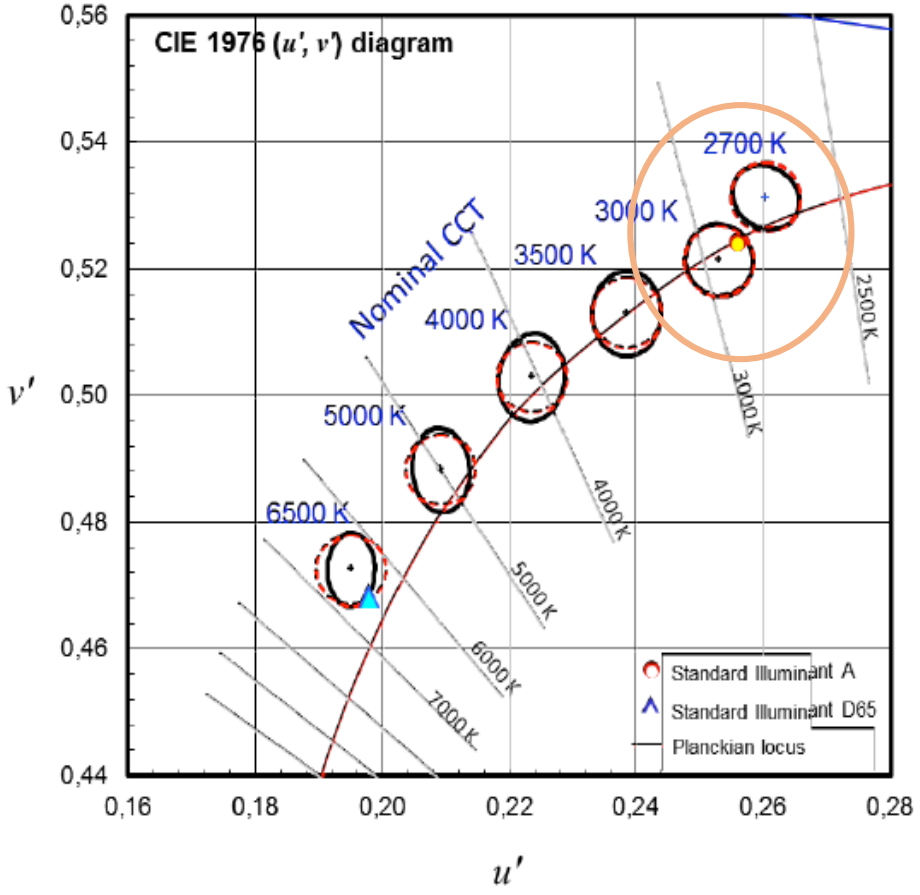
Results of 2019 Experiment



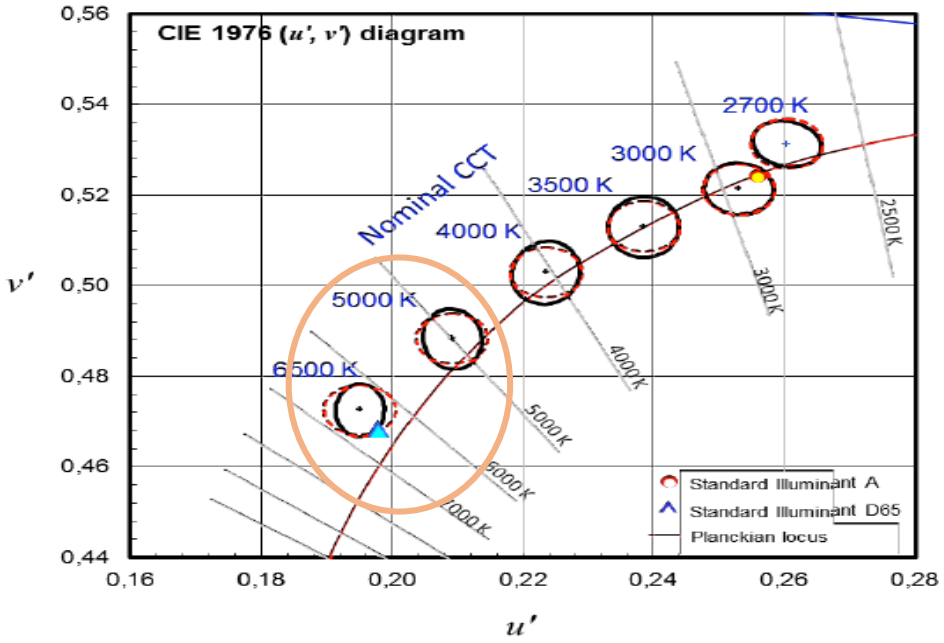


Observation from MacAdam Ellipses

Fig.3 in CIE TN001:2014



Vertical length adjusted to (u,v,)



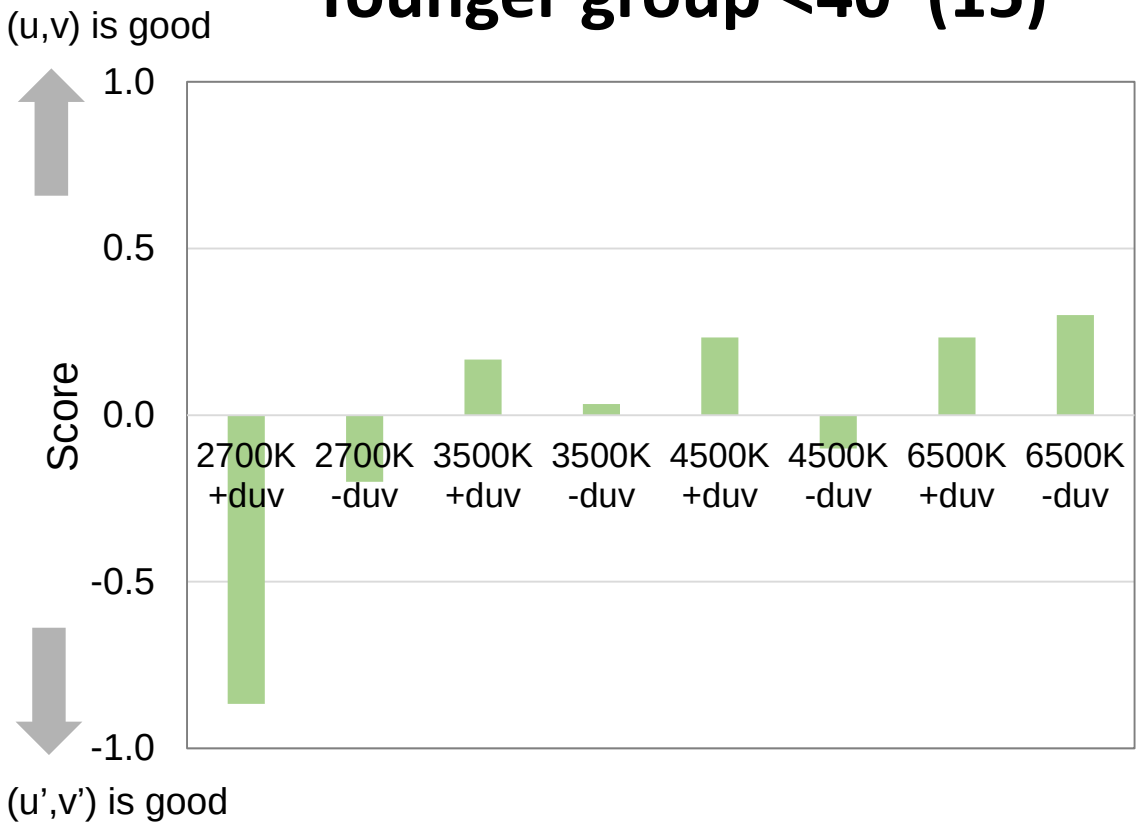
Results – Gender variation

Male (11)

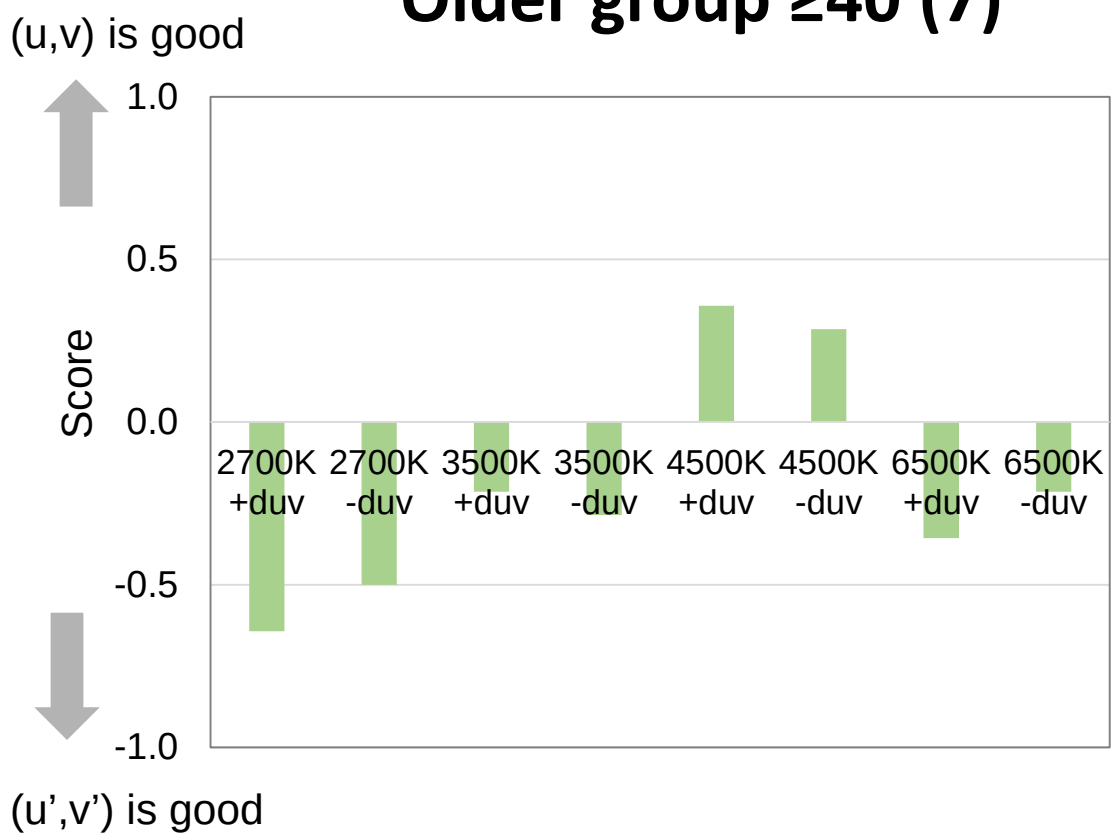
Female (11)

Results – Age variation

Younger group <40 (15)



Older group ≥40 (7)



Conclusions

- Correlation between the values of CCT and perception of CCT has been studied experimentally.
- It is clear that (u', v') chromaticity space has better correlation at low CCTs (2700K or 3000 K) – from 2019 and 2016 results.
- At higher CCTs, the results vary and are not conclusive.
- It is desired that further experiments will be made, including conditions for other applications such as displays.
- These results will be contributed to CIE DR 1-67.

THANK YOU FOR YOUR ATTENTION

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