1st Nordic Conference on

Zero Emission and Plus Energy Buildings

Towards carbon neutral built environments

Relation between daylight availability and electric lighting of real users in a single-family house

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Session 23: Indoor Environment 2

Thursday, Nov 7, 2019

3:30 PM - 4:30 PM

NTNU – Trondheim
Norwegian University of Science and Technology

POLITECNICO DI TORINO

Contents

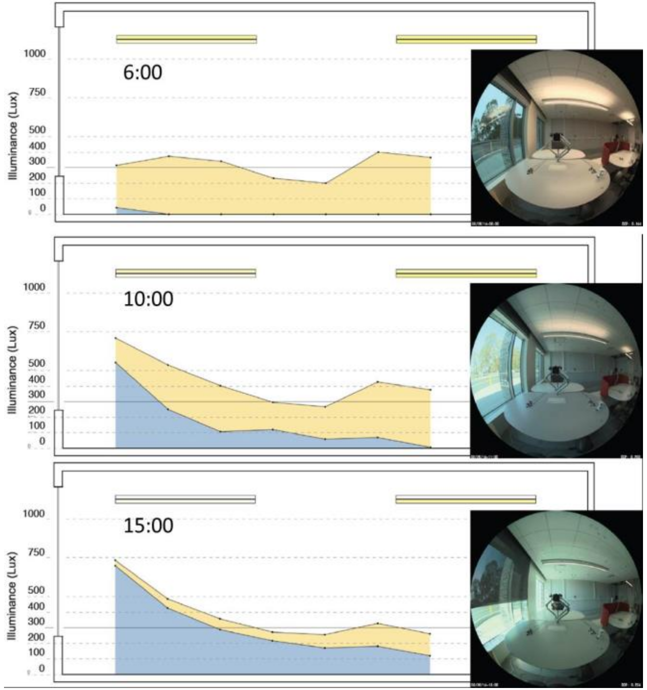
Introduction and Background

BENEFITS

A **homogenous daylight distribution** has relevant **benefits on the building's energy saving, on the human health and on the occupants' well-being**[1].

ENERGY SAVING

Maximizing the sunlight penetrating in the interiors also allows **a reduction of electric energy use for artificial lighting**[2].



Source: facades.lbl.gov

[1] J. Mardaljevic, "Rethinking daylighting and compliance," *SDAR* Journal of Sustainable Design & Applied Research,* vol. 1, no. 3, pp. 1-9, 2013.

[2] O. Walkenhorst, J. Luther, C. Reinhart and J. Timmer, "Dynamic annual daylight simulations based on one-hour and one-minute means of irradiance data," *Solar Energy,* vol. 72, no. 5, pp. 385-395, 2002.

Introduction and Background

OFFICE BUILDINGS vs RESIDENTIAL BUILDINGS

A relationship between increased daylighting and reduced use of electric lighting can be found for office buildings: a decrease in the electric lighting use occurs when a proper range of illuminances is provided on the horizontal work plane[3].

It can be **more challenging to find such a relationship in the context of residential building**, probably because of the **different user behavior in domestic setting**[4].


Photo of living space of ZEB living lab : Nicola Lolli

[3] L. Bellia, F. Fragliasso and E. Stefanizzi, “Daylit offices: A comparison between measured parameters assessing light quality and users' opinions,” *Building and Environment,* vol. 113, pp. 92-106, 2017.

[4] J. Mardaljevic, M. Andersen, N. Roy and J. Christoffersen, “Daylighting metrics for Residential Buildings,” in *CIE 27th Session, July 10th -15th*, Sun City, 2011.

Introduction and Background

PREVIOUS STUDY - RESIDENTIAL DWELLING

The findings demonstrated that, in residential context, **it is rather difficult to find a strong inverse correlation between the daylight availability and the use of artificial lighting**[5].

Unpredictability of users' behavior: users generally do not switch off or dim the light when the internal illuminance owing to natural light increases.

Photo: Anne J. Bruland

LIMITATIONS

The **daylighting** and the **energy for electric lighting** have been **calculated for the whole area** of the building.

[5] G. Lobaccaro, S. Esposito, F. Goia and M. Perino, "Daylighting availability in a living laboratory single family house and implication on electric lighting energy demand," *Energy Procedia,* vol. 122, pp. 601-606, 2017.

Research Questions and Goals

RESEARCH QUESTIONS

1. Is there **a correlation between daylight availability and the use of artificial lighting** in **residential building**?
2. Does **the use of artificial lighting decrease** as much as the **amount of natural light available increases**?

Photo of bedroom west of ZEB living lab : Nicola Lolli

GOALS

- **Higher level of detail** – Regarding rooms with different shape, orientation and intended use (day/night time and activities).
- Deepening to analyze to **the single light sources**.

Does **any significant difference** emerge from the **previous study**?

Case study: The ZEB Living Laboratory

Norwegian single family house reaching **CO_2-neutral construction** (ZEB-OM ambition level) in the Norwegian climate with todays' technologies.

A **living-laboratory** to carry out research on how **users interact with state-of-the-art technologies and low-energy buildings**.

A **building-laboratory** carry out research on advanced building components and systems to achieve **energy flexible buildings**.

Photo: Anne J. Bruland

Monitoring Experiment at ZEB Living Laboratory

PERIOD

October 2015 - April 2016

USERS

Five groups of users moved in the ZEB Living Laboratory and they **used it as their own home** for **twenty-five days each**.

BEHAVIOUR & INSTRUCTIONS

- Users were invited to **continue** with their **routines** and **habits** by **avoiding any unusual behavior**.
- Very **basic information** was provided about the **building operation**.
- **Data of the last week** of the occupational period was considered

TWO STUDENTS

FAMILY x 2

RETIRED COUPLE x 2

Methodology Workflow

The methodology is structured in **two parts**.

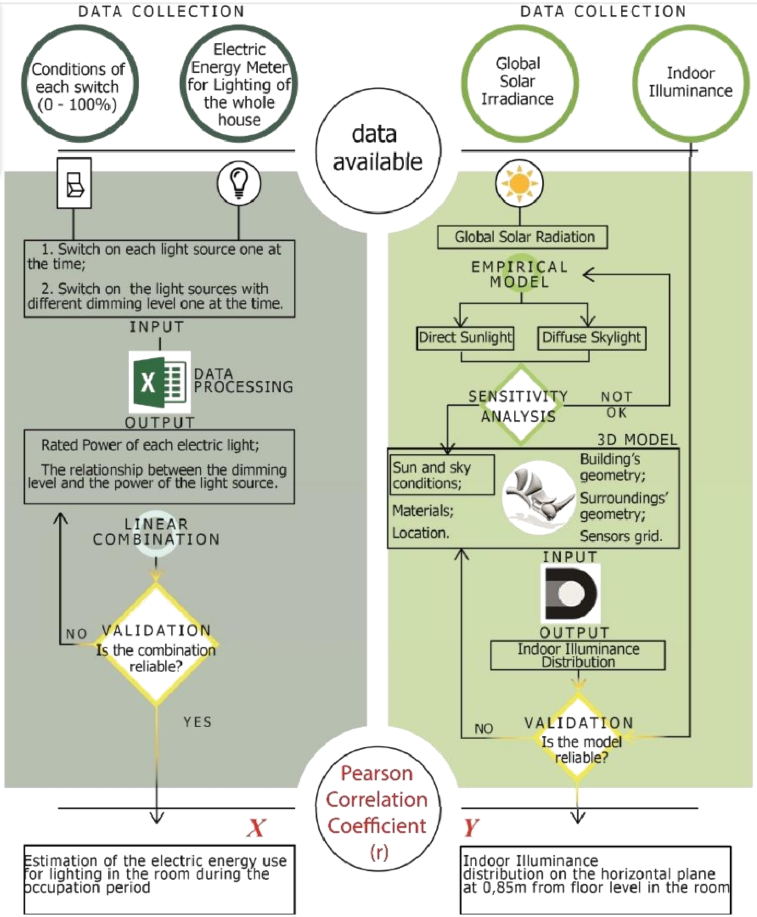
Part 1 - **Calculation** of the **electric energy use for lighting** in the building down to each individual room.

Part 2 - **Estimation** of the **daylighting availability** for the periods of occupancy.

Pearson Correlation Coefficient (r) to assess the correlation between the two variables in each analyzed room:

(i) **Electric use for lighting** in each single room.

(ii) **Average illuminance** on the horizontal plane placed at 0.85 m from the floor level.

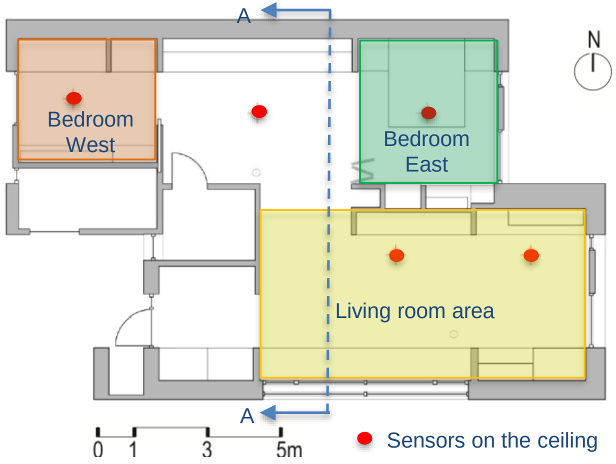


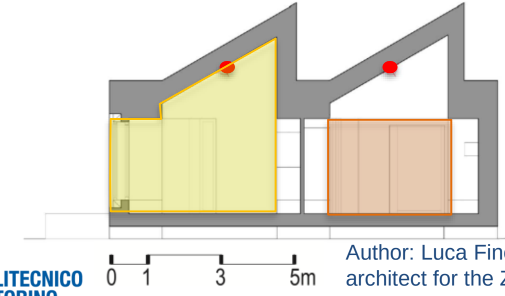
Methodology
Part 1 Electric Energy Use for Lighting

COLLECTION of ILLUMINANCE DATA (indoor environment)

Illuminance sensors in the indoor environment (accuracy of ±10%) placed **on the ceiling** of all analyzed rooms.

Electric energy meter for lighting and **dimmer status** of **each light source** were used for **the characterization of the lighting system** in each room**.**





Section AA

Author: Luca Finocchiaro, main architect for the ZEB Living Lab

Methodology
Part 1 Electric Energy Use for Lighting

COLLECTION of ILLUMINANCE DATA (outdoor environment)

A pyranometer (accuracy of ±3%) was used to measure **global solar irradiance on the horizontal plane**.

Direct measurement of the different components of solar radiation (direct and global diffuse) **was reconstructed from experimental data**.

Methodology
Part 2 Daylight Simulations and Setting Parameters

WEATHER CLIMATE FILE

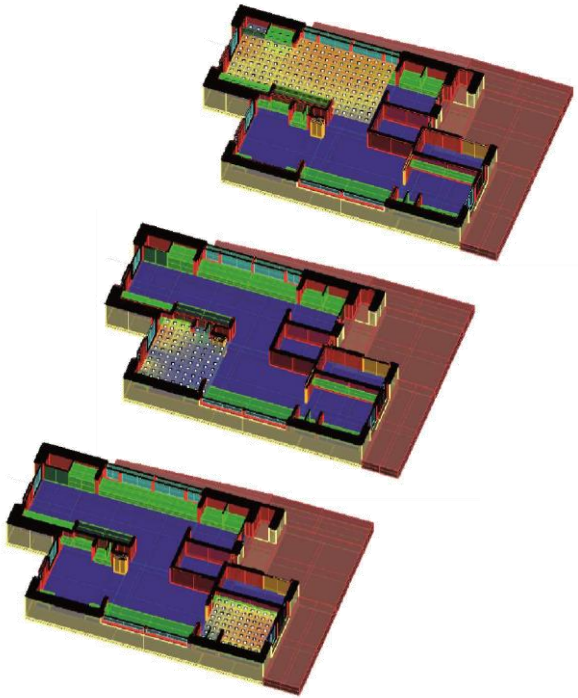
International Weather for Energy Calculations (IWEC) converted in energy plus weather (**.epw**) data file of **Trondheim**.

MODEL

3D model was built in Rhinoceros environment.

SIMULATIONS

Indoor illuminance levels for the analyzed rooms were recreated through **climate-based simulations** using **DIVA-for-Rhino,** a **RADIANCE based software.**



Daylight autonomy analyses in the analyzed room

Methodology
Part 2 Daylight Simulations and Setting Parameters

PARAMETERS

ambient bounces (ab)	ambient divisions (ad)	ambient supersamples (as)	ambient resolution (ar)	ambient accuracy (aa)
5	1024	16	256	0.10

MATERIALS SETTINGS

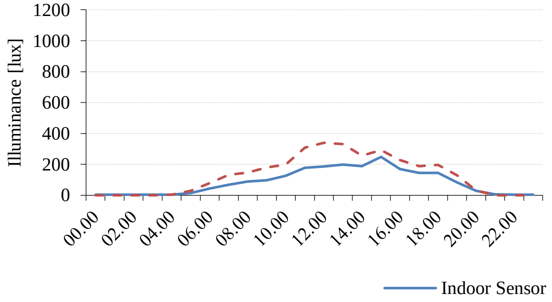
Description	Material/Colors	Radiance material	RGB	Specularity	Roughness
Ceiling	Opaque	WoodenCeiling	0.6/0.4/0.3	0	0
Wall	Opaque	WoodenInteriorWall	0.6/0.4/0.3	0	0
Floor	Opaque	WoodenFloor	0.5/0.3/0.2	0	0.02
Furniture	Opaque	WoodenFurniture	0.5/0.3/0.2	0	0
Single Glazing	Translucent	Glazing_SinglePane_88	0.96/0.96/ 0.96		
Triple Glazing	Translucent	Glazing_TriplePane_Krypton	0.51/0.51/0.51		
Mullions	Opaque/ dark grey	MullionsSheetMetalmatted	0.1/0.1/0.1	0.8	0
Outside Wood	Opaque	OutsideWood	0.5/0.3/0.2	0	0

Visualization outputs of the 3D model

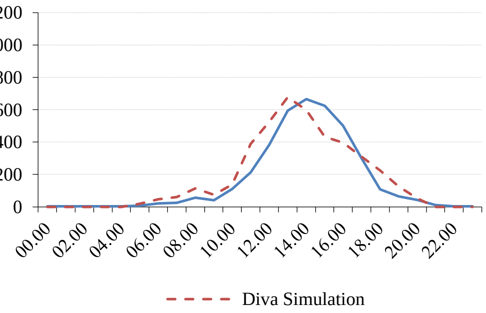
Methodology
Part 2 Model Validation and Sensitivity Analysis

Comparison between the **illuminance values carried out from the analysis of daylight autonomy** and the **values recorded by sensors** installed on the ceiling of the living room.

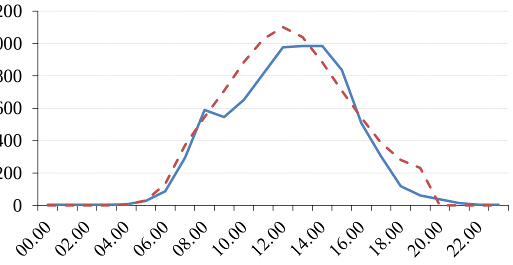
a) Overcast sky conditions (1st of May)



b) Intermediate sky conditions (7th of May)

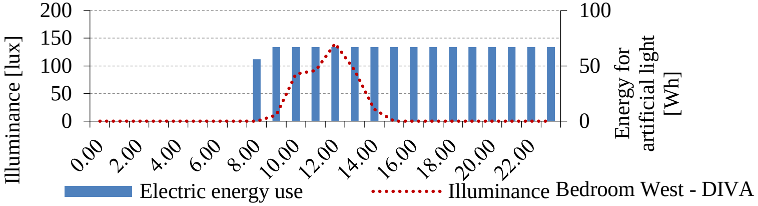


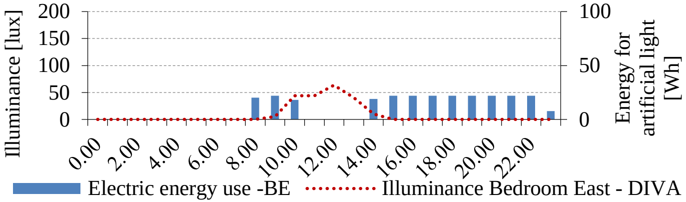
c) Clear sky conditions (9th of May)



Results – Correlation Energy for Lighting / Daylighting

Day	Year Period Users	Pearson Correlation Coefficient r			
		Liv. room	Bed. west	Bed. east	Prev. Study
Day 1		N/A*	N/A	N/A	0,097
Day 2		0,324	**0,565**	-0,040	0,282
Day 3	2015	0,300	0,385	**0,673**	0,388
Day 4	27.11/04.12	-0,392	-0,431	-0,420	-0,398
Day 5	Two students	-0,271	-0,302	-0,279	-0,279
Day 6		**0,021**	-0,066	-0,147	0,325
Day 7		-0,473	N/A	**-0,770**	-0,470
Day 1		**-0,574**	N/A	N/A	-0.531
Day 2		**-0,589**	N/A	**-0,573**	**-0.589**
Day 3	2016	**-0,575**	N/A	N/A	0.013
Day 4	09-15.02	**-0,761**	N/A	N/A	**-0.786**
Day 5	Retired couple	**-0,771**	N/A	-0,588	**-0.796**
Day 6		**-0,732**	N/A	N/A	**-0.769**
Day 7		-0,380	N/A	-0,274	-0.476
Day 1		N/A	N/A	0,455	0.079
Day 2		-0,329	N/A	N/A	-0.085
Day 3	2016	**-0,629**	N/A	N/A	-0.441
Day 4	11-17.04	-0,467	N/A	N/A	-0.650
Day 5	Retired couple	-0,052	N/A	N/A	-0.439
Day 6		-0,282	**0,556**	N/A	-0.348
Day 7		N/A	N/A	0,455	**0.726**





In bold are highlighted all the strong correlations.

* N/A (not-applicable): represent the cases in which there is no electric energy use for lighting (lights switched off) in the room during the daylight hours of the day, therefore it is not possible to assess the correlation.

Author: Luca Finocchiaro, main architect for the ZEB Living Lab

Results – Correlation Energy for Lighting / Daylighting



Day	Year Period Users	Pearson Correlation Coefficient r				Year Period Users	Pearson Correlation Coefficient r			
		Liv. room	Bed. west	Bed. east	Prev. Study		Liv. room	Bed. west	Bed. east	Prev. Study
Day 1	2015 27.11/04.12 Two students	N/A*	N/A	N/A	0,097	2016 18-24.01 Family with two children	N/A	N/A	N/A	-0,367
Day 2		0,324	**0,565**	-0,040	0,282		N/A	N/A	N/A	0,331
Day 3		0,300	0,385	**0,673**	0,388		N/A	N/A	N/A	0,008
Day 4		-0,392	-0,431	-0,420	-0,398		N/A	N/A	N/A	0,380
Day 5		-0,271	-0,302	-0,279	-0,279		N/A	N/A	N/A	0,290
Day 6		**0,021**	-0,066	-0,147	0,325		**0,599**	N/A	N/A	**0,603**
Day 7		-0,473	N/A	**-0,770**	-0,470		-0,485	N/A	N/A	-0,490
Day 1	2016 09-15.02 Retired couple	**-0,574**	N/A	N/A	-0.531	2016 12-18.03 Family with two children	-0,392	-0,460	N/A	0,376
Day 2		**-0,589**	N/A	**-0,573**	**-0.589**		0,192	N/A	N/A	0,172
Day 3		**-0,575**	N/A	N/A	0.013		-0,435	-0,473	-0,348	-0,474
Day 4		**-0,761**	N/A	N/A	**-0.786**		-0,356	-0,503	N/A	0,002
Day 5		**-0,771**	N/A	-0,588	**-0.796**		-0,473	-0,477	-0,429	-0,490
Day 6		**-0,732**	N/A	N/A	**-0.769**		-0,367	-0,415	-0,248	-0,249
Day 7		-0,380	N/A	-0,274	-0.476		0,128	-0,192	0,033	0,170
Day 1	2016 11-17.04 Retired couple	N/A	N/A	0,455	0.079					
Day 2		-0,329	N/A	N/A	-0.085					
Day 3		**-0,629**	N/A	N/A	-0.441					
Day 4		-0,467	N/A	N/A	-0.650					
Day 5		-0,052	N/A	N/A	-0.439					
Day 6		-0,282	**0,556**	N/A	-0.348					
Day 7		N/A	N/A	0,455	**0.726**					

In bold are highlighted all the strong correlations.

* N/A (not-applicable): represent the cases in which there is no electric energy use for lighting (lights switched off) in the room during the daylight hours of the day, therefore it is not possible to assess the correlation.



Author: Luca Finocchiaro, main architect for the ZEB Living Lab

Conclusions

This study **confirmed the main findings** of the previous work[5].

Despite the level of detail for the calculation of daylight availability increased to the individual room, these are the main findings:

- It **cannot be found a strong correlation** between **daylight availability** and **energy for lighting**;
- **It is difficult to obtain a robust correlation in the domestic context of residential buildings** due to the fact that the **users' behaviour is often unpredictable** when they interact with artificial lighting system in their everyday life.
- The **use of electric lights is more dependent** on the **occupancy schedule**, the **users' behaviours,** the **culture**, the **habits** and the **psychological aspects rather than** on the **availability of daylight**.

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