21st November 2024

**Fernando Guerreiro**
**School of Electrical and Electronic Engineering**

Dear Fernando,

Further to the receipt of the report on the examination of your thesis entitled "*Building Integration of a Solar Air Heating System.",* we are pleased to inform you that:

"*The award of PhD is recommended, subject to the inclusion in the thesis of minor corrections and revisions as specified*".

Please find attached the examination report with the list of required corrections.

Minor corrections may take up to three months to complete and I would be grateful if you could amend the thesis as specified on or before 21st February 2025. **Please email one PDF copy of the corrected thesis to giovanna.rampazzo@tudublin.ie and please also send a Word document clearly outlining how and where you have addressed each correction**. Please do not email the thesis directly to examiners.

I trust the above meets with your approval, but should you have any queries, please do not hesitate to contact me.

Kind regards,

Giovanna Rampazzo
Graduate Research School Office
E giovanna.rampazzo@tudublin.ie
T: +353 1 220 6921

*Cc: Prof. Brian Norton, Dr. Michael McKeever, Prof. David Kennedy, Prof. Michael Conlon, Dr. Marek Rebow*

**GRADUATE RESEARCH SCHOOL**

**EXAMINATION REPORT**

**PGR 4C**

## 1.1 Student Details

Student Name: Fernando Guerreiro

School: Electrical and Electronic Engineering

Award: Doctor of Philosophy

## 1.2 Examiner Details

Internal Examiner Name*: Dr John McGrory*

Email Address: *john.mcgrory@tudublin.ie*

External Examiner Name*: Prof. Tapas Kumar Mallick*

Address: *Environment and Sustainability Institute, University of Exeter, Penryn Campus*

*Penryn, TR109FE; UK*

Email Address: *t.k.mallick@exeter.ac.uk*

I confirm I have no interest, relationship or other circumstance which might constitute a conflict of interest, or which might be seen as inappropriate for the role of Examiner. I understand that failure to do so could lead to retraction of an award if a conflict of interest comes to light at a later date.

Signature _____ _____ Date ____12/11/2024___

External examiner
Prof. Tapas Kumar Mallick

Signature ___ _____ Date ___12/11/2024_____

Internal examiner
Dr. John McGrory

## 2. Preliminary Reports on the Thesis

2.1 Preliminary External Examiner Report

University of Exeter

Environment and Sustainability Institute
Faculty of Environment, Science and Economy
Penryn Campus; Cornwall TR10 9FE
United Kingdom
+44
(0)1392 721234
esienquiries@exeter.ac.uk

Date: November 11, 2024

**To Whom It May Concern:**

| | | |
|---|---|---|
| Name of the Candidate | : | *Fernando Superbi Guerreiro* |
| Department | : | School of Electrical & Electronic Engineering |
| Title of the thesis | : | *Building Integration of a Solar Air Heating System* |

**Detailed Report**

This is to confirm that I have thoroughly examined the PhD thesis entitled **"*Building Integration of a Solar Air Heating System*" by *Fernando Superbi Guerreiro***. The study is combination of novel modelling and experimental in relation to the solar air heating system applied to buildings. The thesis is well written and in appropriate manner in relation to the air heating systems. The thesis began with generic introduction and a literature reviews related to the solar air heating systems focusing on absorber surface, glazing cover and airflow rate, which are critical parameters for maximizing the energy transfer from the system. This chapter provided adequate but concise information about different types of concentrating collectors and their limitation for building integration approaches. The rationale for different applications are clearly identified and appropriately referred. The literature review chapter is well written, information, and appropriately presented. All appropriate terminologies, mechanism, issues are discussed. There are several critical analysis is given, which are outstanding – critically and concisely showed information available in the literature.

The chapter 3 is related to the optical modelling and system design analysis. The configuration is well defined and appropriately reflected to the context of the research. The mathematical formulation and the optical modelling for different configuration is represented in an optimal manner. The parametric analysis is well defined and specially in relation to the height of the collector and their optical defects.

The fabrication and experimental analysis is given in chapter 4. The work included outdoor experiments and detailed procedures of the fabrication techniques. A very light material such as carbon fiber has been used for prototype development. Overall, the chapter is well written. The concept is well executed and methodologies for experimentations are appropriately described within the context of the study. The mathematical concept is appropriate and validated against the experimentations. An excellent result and analysis presented here both at the zero airflow and nearly steady state conditions.

A detailed thermal modelling is described in the chapter 6. It has considered mathematical formulation correctly and appropriate level of validation provided for different climatic conditions and also case studies provided adequately.

However, there are some discussions/questions will be asked during the viva are:

- chapter 2, page 29, role of channel dimension in regard to the system design.
- In relation to the optical analysis, does non-uniformity takes place within the absorber plate and is there any effect to the material stability?
- Page 54, why such a configuration (figure 3.1) was considered, and why such specific concentration is considered?
- Figure 3.3 latitude N or S?
- Page 58, what is the effect of truncation apart from saving materials?
- Figure 3.10, number of rays considered?
- Figure 3.16, physical significance of the figure?
- Figure 4.4 What is the rationale for temperature sensors in such places?
- Section 4.3.1 airflow vs. mean temperature? Or what is optimum airflow?
- Chapter 5, grid independent study or how many elements were considered and why?
- Figure 5.21, what can be improved to minimize the energy deficit?

Overall the thesis is in excellent standard, well written, adequately interpreted, provided new knowledge to the reader, highly competitive to the international standard, excellent use of the references in the context of the study and appropriately referred in the context of the solar air heating systems. The thesis should be awarded to PhD, subject to satisfactory viva.

Yours Sincerely,

Yours truly,

**Professor Tapas K Mallick**
Chair in Clean Technologies (Renewable Energy)
Room No: 01.02

Environment and Sustainability Institute; Faculty of Environment, Science and Economy,
University of Exeter; Cornwall Campus; Penryn
Cornwall TR10 9EZ; Tel: 0044 (0) 1326 259465; Email: t.k.mallick@exeter.ac.uk


## 2.2 Preliminary Internal Examiner Report

I confirm that I have thoroughly examined the presented thesis document. The topic is relevant to the current drive to switch from fossil fuels to a more renewable energy paradigm. The literature review includes some of the fundamental aspects of solar collector design. I would argue that this chapter is narrow and could have been broader. It did demonstrate understanding and recognition of the benchmark concepts but did not examine some of the disrupter literature, concepts and technology in this space. The design, modelling, testing and evaluation were also adequate in keeping with the level of PhD work in this area but missing some additional reflection, judgment and curiosity, that would prompt more dept in the design and results and as a consequence is missing some collaborative support literature. The conclusion highlights the students claims of their outcomes, which will be fleshed out in the viva voce. The structure of the conclusion chapter is haphazard in its layout and execution.

In general, the document structure is well laid out, however there are several grammatical and spelling errors, and other edit issues with page numbers and figures in middle of text etc. There are also some issues with declaring variables and variable units being used and in some cases missing.

I see no reason not to complete the viva voce defence for this student.

# 3. Final Reports on the examination

## 3.1. Report on the examination of the thesis

The thesis presents a comprehensive study on the design, modelling, and experimental validation of a solar air heating system for buildings, aiming to maximise energy efficiency through a combination of theoretical and practical approaches. It begins with a well-organised introduction and literature review that contextualize solar air heating systems, examining key parameters such as absorber surfaces, glazing, and airflow rates. These factors are identified as crucial for optimizing heat transfer, and the review provides concise yet thorough insights into the various types of concentrating collectors, their limitations, and integration strategies in building applications. The literature review is especially strong in its critical analyses of previous studies, highlighting current knowledge gaps and appropriately referencing applications.

Chapter 3 details the optical modelling and system design, focusing on configurations and parametric factors like collector height. In Chapter 4, a prototype made from lightweight carbon fiber is tested outdoors, with results validating the model's predictions. Chapter 6 presents comprehensive thermal modelling, validated for various climates and supported by case studies. Overall, the study provides a thorough analysis that advances solar heating integration in buildings.

Overall, this thesis is well-written, effectively interpreted, and contributes new knowledge to the field, placing it at a competitive level internationally. The study makes excellent use of references, appropriately integrating them into the context of solar air heating systems. The thesis demonstrates a high quality of research and should be awarded a PhD.

The examiners recommend publishing 2-3 papers in peer-reviewed journals based on the work presented in this thesis.

## 3.2. Report on the examination of the candidate

The PhD viva voce was conducted using the on-line platform. The candidate delivered a clear and concise 15-min presentation. The presentation was followed by a Q&A session of about 2 hours with a 5 min break.

The PhD candidate defended this thesis with confidence and clarity, demonstrating a deep understanding of the solar air heating system's design, modelling, and experimental validation. He effectively addressed questions on key parameters like absorber surfaces, glazing, and airflow, highlighting the significance of these factors in optimising energy

efficiency. The candidate showcased a comprehensive grasp of both theoretical and experimental aspects, skilfully explaining the study's contributions to the field and its alignment with international developments. His defence was well-prepared, insightful, and underscored the thesis's high academic quality, making a compelling case for awarding the PhD.

### 3.3 Recommendation (Please tick one recommendation)

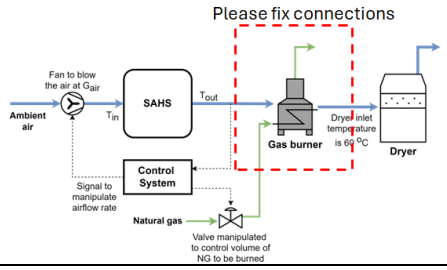
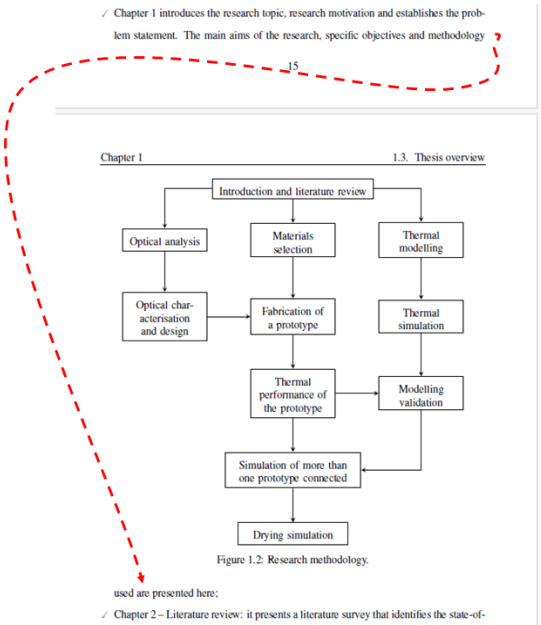
| | | |
|---|---|---|
| 1. | The award is recommended with no corrections required in thesis. | |
| 2. | The award is recommended, subject to inclusion in the thesis of the minor corrections and revisions specified in Section 3.4. | **X** |
| 3. | The award is **NOT** recommended, but re-submission of the thesis is to be permitted subject to the major revisions and the conditions specified in Section 3.4. | |
| 4. | The award is **NOT** recommended but it is recommended that the candidate be awarded the lower award of _____ | |
| 5. | It is recommended that **NO** award be made but a revised thesis may be submitted for examination for the higher award of _____ | |
| 6. | It is recommended that permission be given to the candidate to withdraw the thesis without penalty. | |
| 7. | It is recommended that **NO** award be made. | |

### 3.4 Corrections to Thesis

Please provide **precise details** of any corrections/revisions required to be made to the thesis.

Corrections:

| Item | Correction | FG_Checklist and comments |
|---|---|---|
| 1 | Page numbers need amending. Page numbers in roman numerals (i, ii, iii) after the title page until chapter 1, such as the abstract, declaration, acknowledgement and tables of contents/figures/equations, etc. The title page does not have a page number. The first page of chapter 1 should start the page numbering 1. Between the title and chapter 1 it should be roman numerals. Then ensure to update the page numbers in the Table of contents, table of figures etc. | |
| 2 | In general, there are of spelling and grammar errors, contribution, should be contributions and Bulding should be buildings Pg: 15, Ch: 1, Sect:1.2. Pg 16 overview building, should be an overview of building, it describes physical….. should be…. it describes the physical … Just as an example.<br>The use of an English spell checker, check if it is to be US or UK English, and it would be worth using software such as Grammarly highlight others errors. The document is peppered with these errors. | |
| 3 | For all equations please clearly identify the units of each variable you use and also ensure the variable itself is declared. This is just an example of the issue. What are the units of $U_L$.<br>It needs to be very clear to the reader.<br>For example:<br><br>where $U_L$ is the collectors overall heat loss coefficient in W/(m²K)<br><br>The thermal characterisation of a SAHC relates the thermal efficiency under steady state to each temperature rise normalised by the corresponding solar radiation according to the Hottel-Whillier-Bliss equation, expressed by Eq. (2.3).<br><br>$\eta_{th} = \eta_o - U_L \frac{(T_{abs} - T_{amb})}{I_T}$ (2.3)<br><br>where $U_L$ is the collector's overall heat loss coefficient. The $U_L$ value depends weakly on temperature and, in most cases, it is considered to be constant at typical operating conditions (Rabl, 1985). Lastly, the optical efficiency $\eta_o$ is defined as the ratio between the absorbed and the incident solar radiation. From this equation, $\eta_{th}$ can be plotted against $(T_{abs} - T_{amb})/I_T$, resulting in a linear curve, with $\eta_o$ and $U_L$ as the linear coefficient and the slope, respectively (Goswami, 2015).<br>This needs to be done and checked for every equation.<br><br>Another example of the same:<br>Pg: 20, Ch:2 , Sect:2.1, It standard practice to include the units when declaring a formula or its elements and calculations for the first time for example what units is $I_T$ and what is $Q_u$.<br>Some items in equations are not declared. λv: is Latent heat of vaporization (or condensation). But you do not say it anywhere. | |
| 4 | Solar Air Heating System (SAHS) and CR Concentration Ratios is not in Acronyms, they should be in the Acronyms list. There is one reference at Page 40 after it was used in Pg 38. It is not | |

| | | |
|---|---|---|
| | consistent as you use CR and cr. Please ensure the same acronym structure is used for all your variables. | |
| 5 | $G_{air}$ in the document, images and tables needs to be clarified. What are its units exactly. Also update near equation 4.1 this information. | |
| 6 | Pg: 32, Ch2: , Sect: 2.2 ,What is $a_{abs}$ in equation 2.7. I do not see it explained. Is this $A_{abs}$ in the Latin in List of Symbols. Please double check your symbols and abbreviations. | |
| 7 | Figure 5.20 and other similar images to this please fix the connections between the gas burner and the dryer to accurately reflect the model proposed.<br>  | |
| 8 | It is unnecessary to have a hyphen in some of the paragraphs. In the example below ef-ficiency. But your thesis has a lot of unnecessary inclusions of this type of hyphen.<br>flow rates and also the ones with no flow. The thermal performance of the prototype focused on evaluating the useful energy rate (or energy delivered), collector thermal ef-ficiency and outlet air temperature. The useful heat rate transferred to the airflow is esti- | |
| 9 | In your thesis there are several occasions your sentence is broken with the inclusion of an image. It is not good practice. Finish the sentence before the figure, image or formula is inserted. This is only an example for illustration purposes from your document.<br>  | |
| 10 | You did not declare that the test rig results were not normalised to include variation in the outside air temperature. They are influenced by a hot clear day and a colder clear day. You need to state this in the thesis. | |
| 11 | You use language like fast and moderate and usually. This is not appropriate language for a thesis. Amend | |

| | | |
|---|---|---|
| | Pg: 28, Ch:2 , Sect:2.1 , what is fast and moderate…..Ammari (2003) simulated a single pass GAHC and found that the thermal efficiency increased fast until a certain level of volumetric flow rate and then it increased moderately. What about laminar or turbulent air flow in the chamber.<br>The Nusselt number is usually a function of the Reynolds number, which is proportional to the air velocity.<br>The absorber surfaces of SAHCs are usually metal plates.<br>then it increased moderately | |
| 12 | Pg: 31, Ch2: , Sect: 2.2 ,Compound parabolic concentrator (CPC): It is designed from two distinct parabolic segments, where the focus of each one is located at the opposing absorber surface end points. The axes of the parabolic segments are oriented away from the CPC axis by the acceptance angle $\theta_a$. The slope of the reflector surfaces at the aperture is parallel to the optical axis for untruncated CPCs; It must be important as you have clearly stated it, could you elaborate on what this is and why is it important to your design. | |
| 13 | Your thesis states "It is defined as the ratio of the heat transferred to the airflow to the maximum possible heat transfer, if the outlet air temperature was heated to the absorber surface temperature (Kutscher, 1994)." Is that even possible to have the outlet temp of the air same as the absorber surface…there was 100% transfer of heat from the absorber to the air. | |
| 14 | Both examiners consider that the distribution of heat from the thermocouples as laid out in Figure 4.4 and analysis of the variation in temperature between the probes has also considerable merit would be of value to your work. We also feel this data has importance to the verification of your 3D model. | |
| 15 | Pg: 20, Ch 2: , Sect: 2.1, "It is usual to calculate the efficiency based on the air temperature, as it is more practical to measure it rather than the temperature of the absorber surface." Who said that, where is your evidence that backs up that statement. | |
| 16 | Pg: 20, Ch 2: , Sect: 2.1, There is "temperatures $T_{in}$ and $T_{in}$ at the". "(in Heat Transfer textbooks it is also known as heat exchange effectiveness)". Pg 20, What textbooks. Also spot the error in "temperatures $T_{in}$ and $T_{in}$ | |
| 17 | Page 56, figure 3.3 latitude should be N or S | |
| 18 | Page 63, "*1 ray per mm2 of aperture",* add a sentence that high rays density has no effect to the optical efficiency but it increases computing power. | |
| 19 | Page 90, 'figure 4.8' add a figure indicating all temperature measurements as given in figure 4.4. This figure should show highest and lowest measured temperature value which you need to rationalise to the optical modelling and localised peak energy density. | |
| 20 | Both examiners consider that the Chapter 6 Conclusion requires some work. It reads rushed, haphazard and unstructured. It is like an afterthought.<br>By way of a suggestion.<br>6.1. Introduction<br>Describe the chapter layout. Summarise the background of the project. Then continue by saying the goals of the project are revisited and a clear explanation of how that goal has been achieved is given in section 6.2. The future research potential of the project is described in section 6.3. Finally, the conclusion is given in section 6.4 | |

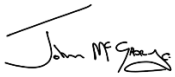
| | | |
|---|---|---|
| | 6.2 Revisit Goals (make sure you are clear on the novelty and your precise contribution to the body of knowledge.<br>6. 3 Future work<br>6.4 Conclusion | |

3.5 Other Specific Requirements

Please provide **precise details** of any other specific requirements, such as the need for a second oral examination of the candidate.

Signature  Date 13/11/2024

External examiner
Prof. Tapas Kumar Mallick

Signature  Date 12/11/2024

Internal examiner
Dr. John McGrory

Signature  Date 12/11/2024

Chairperson

## 4. Corrected Thesis

In accordance with the recommendations of the examiners ie The award is recommended, subject to inclusion in the thesis of the minor corrections and revisions specified in Section 3.4, I confirm I have read the corrected thesis and the minor corrections and/or revisions have

been carried out ☐

NOT been carried out ☐

Signature _____ Date _____
Internal Examiner

## 5. Award

I certify that the final recommendation of the examiners has been considered by the Graduate Research School Board and details provided to the University Programme Board for approval of award to the candidate.

Signature _____ Date _____
Chairperson, Graduate Research School Board