APPLICATION FOR THE PROMOTION TO THE POST OF ASSOCIATE PROFESSOR

UNIVERSITY OF VOCATIONAL TECHNOLOGY

Manamendra Patabendige Kasun Chinthaka Nandapala

Senior Lecturer II, Department of Construction Technology

October, 2024

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Summary of the Application

Section 1

Teaching, Scholarship and Academic Development

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1.1

Academic/Professional Preparation

1.1.1

As a resource person in Seminar/Workshop/Planning of staff Development Programme

1.1.1(1)

Resource person - Induction Programme for new academic staff :

2022

Please Refer the Next Page

UNIVERSITY OF VOCATIONAL TECHNOLOGY
Staff Development Centre (SDC)

INDUCTION PROGRAMME FOR NEW ACADEMIC STAFF - 2022

Date: Thursday, 01st of September 2022 (9.00am – 03.00pm)
Venue: Model Classroom, 3rd Floor, New Building, University of Vocational Technology
Resource persons:

1) Mr. Sudath Liyanage - Dean/Faculty of Education
2) Dr. Ravi Koggalage - Dean/Faculty of Engineering Technology
3) Ms. Nilmini Diyabedanage - Director General (DG)
4) Dr. Kasun Nandapala - Director/AAQA
5) Dr. D.D.D. Suraweera – Senior Lecturer, Department of Electrical & Electronics Technology
6) Dr. Roshani Palliyaguru - Director/SDC
7) Mr. Dilantha Ratnayake – Head/Department of Film and Television Production Technology

Topic	Resource Person	Time	Duration
OVERVIEW OF UOVT (9.00 am - 10.30 am)			
Welcome		9.00am-9.03am	03 Mins
Opening address	Vice Chancellor	9.03am-9.10am	07 Mins
History of the UoVT	Dr. D.D.D. Suraweera	9.10am-9.45am	35 Mins
Overview of the TVET sector and TVEC			
Positioning of UoVT within the TVET sector and the conventional university sector in Sri Lanka			
UoVT at a glance (Student profiles, Student recruitments, student admission procedures, etc., including University Colleges, their functions, and relationship with the UoVT)	Dr. Kasun Nandapala (Director/AAQA)	9.45am-10.00am	15 Mins
UoVT's institutional and organizational arrangements (institutional structure etc.)	Ms. Nilmini Diyabedanage (DG)	10.00am-10.30am	30 Mins
University norms and culture			

Applicability of UGC circulars UoVT's expectations of staff			
Tea Break (10.30 am - 11.00am)			
THINGS YOU SHOULD KNOW AS AN ACADEMIC AT UOVT (11.00 am - 1.00 pm)			
Acts, Ordinance, By-laws, Rules, and Regulations Codes of practices, policies Staff workload and flexible working	Dr. D.D.D. Suraweera	11.00am-11.35am	35 Mins
Staff leave Staff recruitments, confirmation, and promotional procedures Administrative procedures (Administrative regulations)	Ms. Nilmini Diyabedanage (DG)	11.35am-11.55am	20 Mins
Teaching and learning culture CTHE Programme	Mr. Sudath Liyanage	11.55am-12.15pm	20 Mins
Our enterprise, strengthening communities and enabling partners	Dr. Ravi Koggalage	12.15pm-12.30pm	15 Mins
Research allowance and overview of the research programme Personal development and etiquettes Role of SDC Proposed staff mentoring programme	Dr. Roshani Palliyaguru (Director/SDC)	12.30pm-12.45pm	15 Mins
Internal facilities, societies, platforms etc. available for staff	Mr. Dilantha Ratnayake	12.45pm-1.00pm	15 Mins
Lunch Break (1.00 pm - 2.00pm)			
THINGS YOU SHOULD KNOW AS A STUDENT FACILITATOR (2.00 pm – 3.00pm)			
Quality assurance procedures (Teaching, learning, and assessments) Programme accreditations Student feedback, peer observations etc.	Dr. Kasun Nandapala (Director/AAQA)	2.00pm-3.00pm	60 Mins

1.1.1(2)

Resource Person, Advanced Professional Course for Green Accreditation of the Green Buliding Council of Sri Lanka : Intakes 2-10

Please Refer the Next Page

From: **Education GBCSL** education.gbcsl@gmail.com
Subject: Reminder: Lecture Schedule of Advanced Professional Course Intake 02 - Date : 29th Feb 2020
Date: 11 February 2020 at 11:20
To: Kasun Nandapala mpkcnandapala@gmail.com
Cc: Sri Lanka Green Building Council srilankagbc@gmail.com

EG

Dear Sir,

This is a kind reminder regarding the lecture in the Advanced Professional Course for Green Accreditation Intake 02.

The details of the respective lecture are as below.

Topic : Energy Modelling Techniques through Design Builder Software

Date : Saturday, 29th February 2020

Time : 08.30 A.M. - 12.15 P.M.

Venue: Narayanasamy Conference Hall, Hector Kobbekaduwa Agrarian Research And Training Institute (HARTI), Colombo 07
Google map link to the location: https://goo.gl/maps/5Y6DyxQsWkM2

Medium of the program – English

Audience

A group of, about 40 Associate Professionals of the GBCSL including Charted Engineers, Charted Architects, Quantity Surveyors, Environmentalists and other Construction industry-related professionals (Degree holders or professionals with more than 06 years of experience in the similar field)

GBCSL is looking forward to share your expertise in the given area which merged with your countless experiences in the field.

Thank you in advance

Kind Regards,

Vindya Baddewithana
Coordinator-Education, Training & Research
Green Building Council of Sri Lanka
120/10, Vidya Mandiraya,Vidya Mawatha,Colombo 07.

Tel: +94 112679130, +94 77 3147877

Email: office@srilankagbc.org

Web: www.srilankagbc.org

'Committed Leadership in Sustainability'

From: **Education GBCSL** education.gbcsl@gmail.com
Subject: Lecture Details: Advanced Professional Training Program, January Intake (Batch 4)
Date: 20 January 2021 at 20:42
To: Dr Kasun Nandapala kasuncn@gmail.com
Cc: events GBCSL events.gbcsl@gmail.com, Lionel Nawagamuwa lionel.nawagamuwa@gmail.com, Chairman GBCSL chairmangbcsl@gmail.com

EG

Dear Sir,

Kindly find the details of your lecture in the Advanced Professional Training Program, January Intake 2021.

Topic	Energy Modeling Techniques through Design Builder Software
Tentative Date	7th Sunday, February
Tentative Time **Group 1:** **Group 2:**	 8.30 AM – 12.30 PM (4 hours including 15-minute tea break) 1.30 PM – 5.30 PM (4 hours including 15-minute tea break)
Lecture Mode	Classroom sessions (Hector Kobbekaduwa Agrarian Research Institute)
Audience	A diverse group of, about 20 - 30 Associate Professionals and LEED Professionals of the GBCSL including Chartered Engineers, Architects, Quantity Surveyors, Managers, Environmentalists, and other Construction industry-related professionals (Degree holders or professionals with more than 06 years of experience in a similar field)
Lecture Notes	Circulated among the participants prior to the lecture

GBCSL is looking forward to sharing your expertise in the given area which merged with your countless experiences in the field.

For further inquiries, please contact me on 071 2365661.

Thank you in advance,

Kind Regards,

KM Semini Hasanthi

Executive
Education, Training & Research Division
Green Building Council of Sri Lanka
120/10, Vidya Mandiraya,Vidya Mawatha,Colombo 07.

Email: office@srilankagbc.org
Web: www.srilankagbc.org

From: **Education GBCSL** education.gbcsl@gmail.com
Subject: Lecture Details: Advanced Professional Training Program, July Intake (Batch 5)
Date: 25 June 2021 at 13:13
To: Dr Kasun Nandapala kasuncn@gmail.com
Cc: Chairman GBCSL chairmangbcsl@gmail.com, Lionel Nawagamuwa lionel.nawagamuwa@gmail.com, events GBCSL events.gbcsl@gmail.com

Dear Sir,

Kindly find the details of your lecture in the Advanced Professional Training Program, July Intake 2021.

Topic	Energy Modelling Techniques through Design Builder Software
Tentative Date	16 July 2021 (Friday) - Lecture Part 1 19 July 2021 (Monday) - Lecture Part 2
Tentative Time	7.30 PM – 9.00 PM - Lecture Part 1 7.30 PM – 9.00 PM - Lecture Part 2
Lecture Mode	Online
Audience	A diverse group of, about 35 or 40 Associate Professionals and LEED Professionals of the GBCSL including Chartered Engineers, Architects, Quantity Surveyors, Managers, Environmentalists, and other Construction industry-related professionals (Degree holders or professionals with more than 06 years of experience in the similar field)
Lecture Notes	Circulated among the participants prior to the lecture

GBCSL is looking forward to sharing your expertise in the given area which merged with your countless experiences in the field.
For further inquiries, please contact me on 071 2365661.

Thank you in advance,

Kind Regards,

KM Semini Hasanthi

Executive
Education, Training & Research Division
Green Building Council of Sri Lanka
120/10, Vidya Mandiraya,Vidya Mawatha,Colombo 07.

Email: office@srilankagbc.org
Web: www.srilankagbc.org

'Committed Leadership in Sustainability'

From: **Sadeepa Dinali** education.gbcsl@gmail.com
Subject: Re: Lecture Details: Advanced Professional Training Program, June Intake (Batch 6)
Date: 15 July 2022 at 13:25
To: Dr Kasun Nandapala kasuncn@gmail.com
Cc: Chairman GBCSL chairmangbcsl@gmail.com, Lionel Nawagamuwa lionel.nawagamuwa@gmail.com, Upeksha - GBCSL gm.gbcsl@gmail.com

Dear Sir,

Kindly find the **Rescheduled Details** of your lecture in the Advanced Professional Training Program, June Intake 2022.

Topic	**Energy Modelling Techniques through Design Builder Software**
Tentative Date	**July 18, 2022 (Monday)**
Tentative Time	**6.30 PM – 10.00 PM**
Lecture Mode	**Online**
Audience	**A diverse group of, Associate Professionals and LEED Professionals of the GBCSL including Chartered Engineers, Architects, Quantity Surveyors, Managers, Environmentalists, and other Construction industry-related professionals (Degree holders or professionals with more than 06 years of experience in a similar field)**
Lecture Notes	**Circulated among the participants prior to the lecture**

GBCSL is looking forward to sharing your expertise in the given area which merged with your countless experiences in the field.

For further inquiries, please contact me on 071 649 648 5.

Thank you in advance,
Sadeepa Dinali **BA. (Special) in Env. Mgt**
Management Trainee - Education, Training and Research

Green Building Council of Sri Lanka

A : 120/10, Vidya Mandiraya,Vidya Mawatha,Colombo 07
T/E : +94 11 267 9130 l+94 71 649 6485l education.gbcsl@gmail.com
W : www.srilankagbc.org

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On Fri, 1 Jul 2022 at 14:02, Sadeepa Dinali <education.gbcsl@gmail.com> wrote:

Dear Sir,

This is a ***gentle reminder*** of your lecture scheduled under the Advanced Professional Training Program - Intake 6 (details are given below).

Topic	**Energy Modelling Techniques through Design**

From: **Sadeepa Dinali** education.gbcsl@gmail.com
Subject: Lecture Details: Advanced Professional Training Program - January Intake (Batch 7)
Date: 17 January 2023 at 16:56
To: Dr Kasun Nandapala kasuncn@gmail.com
Cc: Chairman GBCSL chairmangbcsl@gmail.com, Lionel Nawagamuwa lionel.nawagamuwa@gmail.com, Upeksha - GBCSL gm.gbcsl@gmail.com

SD

Dear Sir,

We have planned to conduct Advanced Professional Training Program, Intake 07 on the 27th, 28th and 29th of January.

Kindly find the details below of your lecture.

Topic	**Energy Modeling Techniques through Design Builder Software**
Tentative Date	**January 29, 2023 (Sunday)**
Tentative Time	**8.30 AM – 12.15 PM**
Lecture Mode	**Physical**
Venue	**120/10A, Science Tower, Vidya Mawatha, Colombo 07**
Audience	**A diverse group of, Associate Professionals and LEED Professionals of the GBCSL including Chartered Engineers, Architects, Quantity Surveyors, Managers, Environmentalists, and other Construction industry-related professionals (Degree holders or professionals with more than 06 years of experience in a similar field)**

GBCSL is looking forward to sharing your expertise in the given area which merged with your countless experiences in the field.

For further inquiries, please contact me on 071 649 648 5.

Thank you in advance,
Sadeepa Dinali **BA. (Special) in Env. Mgt**

Executive - Education, Training and Research

Green Building Council of Sri Lanka

A	:	120/10, Vidya Mandiraya,Vidya Mawatha,Colombo 07
T/E	:	+94 11 267 9130 I+94 71 649 6485I education.gbcsl@gmail.com
W	:	www.srilankagbc.org

'Committed Leadership in Sustainability'

From: **Sadeepa Dinali** education.gbcsl@gmail.com
Subject: Rescheduled - 29th July - Advanced Professional Training Program - July Intake (Batch 8)
Date: 12 June 2023 at 11:34
To: Dr Kasun Nandapala kasuncn@gmail.com
Cc: Chairman GBCSL chairmangbcsl@gmail.com, Lionel Nawagamuwa lionel.nawagamuwa@gmail.com, Upeksha - GBCSL gm.gbcsl@gmail.com

SD

Dear Sir,

We kindly inform you that we had to **reschedule** the Advanced Professional Training Program, Intake 08 on the **29th of July.**

Kindly find the details below of your lecture.

Topic	**Energy Modeling Techniques through Design Builder Software**
Tentative Date	**July 29, 2023 (Saturday)**
Tentative Time	**10.45 AM – 03.00 PM**
Lecture Mode	**Physical**
Venue	**120/10A, Science Tower, Vidya Mawatha, Colombo 07**
Audience	**A diverse group of, Associate Professionals and LEED Professionals of the GBCSL including Chartered Engineers, Architects, Quantity Surveyors, Managers, Environmentalists, and other Construction industry-related professionals (Degree holders or professionals with more than 06 years of experience in a similar field)**

GBCSL is looking forward to sharing your expertise in the given area which merged with your countless experiences in the field.

For further inquiries, please contact me on 071 649 648 5.

Thank you in advance,

Sadeepa Dinali **BA. (Special) in Env. Mgt**

Executive - Education, Training and Research

Green Building Council of Sri Lanka

A : 120/10, Vidya Mandiraya,Vidya Mawatha,Colombo 07
T/E : +94 11 267 9130 I+94 71 649 6485I education.gbcsl@gmail.com
W : www.srilankagbc.org

'Committed Leadership in Sustainability'

Disclaimer:

From: **Dinushika- GBCSL** events.gbcsl@gmail.com
Subject: Re: Lecture Details I Advanced Professional Training Program - Intake 09 I PHYSICAL
Date: 21 March 2024 at 09:35
To: Kasun Nandapala kasuncn@gmail.com

EG

Dear Sir,

Kindly find the details below of your lecture.

Topic	Energy Modeling Techniques through Design Builder Software
Date	**27th April, 2024 (Saturday)**
Time	**08.30 AM-12.15 PM**
Lecture Mode	**Online**
Venue	Sri Lanka Institute of Development Administration **(SLIDA)**, 28/10, Malalasekara Mawatha, Colombo 07
Audience	A diverse group of, Associate Professionals and LEED Professionals of the GBCSL including Chartered Engineers, Architects, Quantity Surveyors, Managers, Environmentalists, and other Construction industry-related professionals (Degree holders or professionals with more than 06 years of experience in a similar field)

Kind regards!
Dinushika Karunarathna

Assistant Manager

Education, Training and Research Division

Green Building Council of Sri Lanka

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mgttrg.gbcsl@gmail.com/events.gbcsl@gmail.com
W : www.srilankagbc.org

GREEN
BUILDING
COUNCIL OF
SRI LANKA
'Committed Leadership in Sustainability'

From: **Dinushika- GBCSL** events.gbcsl@gmail.com
Subject: Lecture Details: Advanced Professional Training Program I Intake 10
Date: 2 September 2024 at 11:19
To: Kasun Nandapala kasuncn@gmail.com
Cc: Lionel GBCSL lionel.nawagamuwa@gmail.com, Chairman GBCSL chairmangbcsl@gmail.com, Education GBCSL education.gbcsl@gmail.com

EG

Dear Sir,

Thank you for accepting our invitation. I've included the details of your lecture below.

Topic	Energy Modeling Techniques through Design Builder Software
Date	**October 05, 2024 (Saturday)**
Time	**08.30 AM – 12.30 PM**
Lecture Mode	**Physical**
Venue	We'll be informed later
Audience	**A diverse group of, Associate Professionals and LEED Professionals of the GBCSL including Chartered Engineers, Architects, Quantity Surveyors, Managers, Environmentalists, and other Construction industry-related professionals (Degree holders or professionals with more than 06 years of experience in a similar field)**

GBCSL is looking forward to sharing your expertise in the given area which merged with your countless experiences in the field.

For further inquiries, don't hesitate to get in touch with me on 071 181 055 2.

Kind regards!
Dinushika Karunarathna

Assistant Manager

Education, Training and Research Division

Green Building Council of Sri Lanka

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GREEN BUILDING COUNCIL OF SRI LANKA
'Committed Leadership in Sustainability'

1.1.1(3)

Resource Person, Certificate Course on “Corporate Environmental Sustainability by National Cleaner Production of Sri Lanka : 2021 - 2024

Please Refer the Next Page

From: **Nadeeshani Fernando** nadeeshani.ncpc@gmail.com
Subject: Invitation for conducting a Lecture - NCPC
Date: 28 January 2021 at 16:05
To: kasuncn@gmail.com
Cc: events.gbcsl@gmail.com, iresha chandanie iresha.ch@gmail.com

NF

Dear Dr. Nandapala,

National Cleaner Production Centre (NCPC) has organized a certificate course on" Corporate Environmental Sustainability through Greening the Industries". This programme will be conducted in Hotel Janaki, 43, Fife Road, Havelock Road, Colombo 5,

https://www.google.lk/maps/place/Hotel+Janaki/@6.8907823,79.8675623,17z/data=!3m1!4b1!4m8!3m7!1s0x3ae25bd23925cbf1:0x32f66ab5bc724bd4!5m2!4m1!1i2!8m2!3d6.8907823!4d79.869751

We would be pleased to invite you to make a presentation on this programme on the following topic in English Medium.

Topics : Green buildings and Constructions, Green building rating systems, Leads certification
Date : 29th January 2021
Time : 10.30 a.m to 12.30 p.m

We have to provide lecture notes/handouts to all participants of the above programme. **the format of the presentation slides is attached herewith**. Hereby we kindly request you to forward your lecture notes/handouts by tomorrow morning.

Kindly confirm your availability. Thank you,

--
Thank You,
Regards,

Nadeeshani Fernando | Programme Officer

National Cleaner Production Centre, Sri Lanka
66/1, Dewala Road, Nugegoda.
Tel: +94112822272/3
Mobile: +94763100467
Fax: +94112822274
Email: nadeeshani.ncpc@gmail.com

Presentation format.pptx

From: **Iresha Gurusinghe** iresha.ch@gmail.com
Subject: Invitation for conducting a Lecture - NCPC 2022
Date: 20 June 2022 at 09:04
To: Kasun Nandapala kasuncn@gmail.com

CM

Dear Dr. Nandapala,

A certificate course on "Corporate Environmental Sustainability through Greening the Industries" has been organized by the National Cleaner Production Centre (NCPC). This session will be held at Hotel Janaki, 43 Fife Road, Havelock Road, Colombo 5.
We are delighted to invite you to give a presentation on these programs on the following topic in English.

Topics : Green Buildings and Constructions, Green building rating systems,
Lead certification
Date : 08th July 2022
Time : 10.30 a.m to 12.30 p.m

We have to provide lecture notes/handouts to all participants of the above programme. **the format of the presentation slides is attached herewith**. Hereby we kindly request you to forward your lecture notes/handouts one day prior to the lecture date.

Kindly confirm your availability

Thank you,

Best Regards,

Iresha Gurusinghe, BSc (Hons), MSc, CEnvP | Senior RECP Expert

National Cleaner Production Centre, Sri Lanka

66/1, Dewala Road, Nugegoda, Sri Lanka
Tel: +9411 282 2272/3

Fax: +9411 282 2272/3
Mobile: +9476 316 2448

From: **Chamal Manage** chamal.ncpc@gmail.com
Subject: INVITATION to conduct a lecture in Certificate Course on "Corporate Environmental Sustainability through Greening the Industries"
Date: 17 May 2023 at 23:07
To: kasuncn@gmail.com
Cc: Nadeeshani Fernando nadeeshani.ncpc@gmail.com, Madhubhashani Weerasinghe madhubhashani.ncpc@gmail.com

CM

Dear Dr. Kasun Nandapala
Greetings from NCPC

National Cleaner Production Centre (NCPC), Sri Lanka is annually conducting a Certificate Course on "Corporate Environmental Sustainability through Greening the Industries" for responding to build the participant's capacity to lead the industry's greening process as the organization's environment/sustainability team and to give sufficient expertise to advise the organization's management on green initiatives.

This is a Ten-day course consisting 9-days physical classroom sessions with lectures, assignments, case studies and one day site visit to a given Industry. This session will be held **at Best Western Elyon Colombo – 05 for ten consecutive Fridays starting from 16th June 2023**

We are delighted to invite you to deliver a lecture with a presentation on this program on the following topic in English.

Date : 07th July
Duration : Two hours (from 10.30hrs. to 12.30hrs.)
Topic : Green buildings and Constructions, Green building rating systems, Leads certification

NCPC will pay Rs. 7000.00 (including transport allowance) for your valuable contribution

The format of the presentation slides is attached herewith. Hereby we kindly request you to forward your lecture notes/handouts before the lecture since it is required to provide lecture notes/handouts to all participants of the above programme.

Kindly confirm your availability for the above date and time and do not hesitate to contact the undersigned for any clarification in this regard

Thank you

--
Chamal Niroshana Manage
BSc, MSc (Env.Mgt.), PGDip (Env.Sc.), CEnvP, MIEP(SL)
Head, Environmental Management Division/Senior RECP Expert
National Cleaner Production Centre

No: 66/1, Devala Road, Nugegoda, Sri Lanka
Tel : +94112822272/+940112822273 (Ext - 12)
Fax : +94112822274
Mob : +940763162448, +94718680116
Email : chamal.ncpc@gmail.com
Web : www.ncpcsrilanka.org

Presentation format.pptx

From: **Chamal Manage** chamal.ncpc@gmail.com
Subject: NVITATION to conduct a lecture in Certificate Course on "Corporate Environmental Sustainability through Greening the Industries"
Date: 18 June 2024 at 11:57
To: Kasun Nandapala kasuncn@gmail.com

CM

Dear Dr. Nabdapala
Greetings from NCPC

This refers further to the telephone conversation I had with you with regards to the captioned matter. It is much appreciated your positive response and confirmation on the same. I do hereby send the invitation for conducting the lecture mentioned in the text below.

National Cleaner Production Centre (NCPC), Sri Lanka is annually conducting a Certificate Course on "Corporate Environmental Sustainability through Greening the Industries" for responding to build the participant's capacity to lead the industry's greening process as the organization's environment/sustainability team and to give sufficient expertise to advise the organization's management on green initiatives.

This is a Ten-day course conducted on 10 consecutive Fridays from 28th June 2024 consisting of 9-days consists of classroom sessions, in field assessment and home based assignments

More details of the program are given on our website https://www.ncpcsrilanka.org/training/greening-the-industries/

We are delighted to invite you to deliver lectures with a presentation on this program on the following topic in English.

Date : 19th July 2024
Venue : Post Graduate Institute of Management (PIM), Colombo – 08
Duration : Two hours (from 10.30 to 12.30 hrs.)
Topic : Green Building and Constructions, Green Building Rating systems, Leads certification

NCPC will pay Rs. 7,000.00 (including transport allowance) for your valuable contribution

Hereby we kindly request you to **forward your lecture notes/handouts** before the lecture since it is required to provide lecture notes/handouts to all participants of the above programme.

I will fix the time for your lectures on **19th July** and please contact the undersigned for any clarification in this regard.

--

--
Chamal Niroshana Manage
BSc, MSc (Env.Mgt.), PGDip (Env.Sc.), CEnvP, MIEP(SL)
Team Leader, Environmental Management Division/Senior RECP Expert

Sri Lanka

National Cleaner Production Centre
No: 66/1, Devala Road, Nugegoda, Sri LankaTel : +94112822272/+940112822273 (Ext - 12)
Fax : +94112822274
Mob : +940763162448, +94718680116
Email : chamal.ncpc@gmail.com
Web : www.ncpcsrilanka.org

1.1.1(4)

Resource Person, Managerial Competency Development Programme (MCDP) by National Human Resource Development Council : 2018

Please Refer the Next Page

NATIONAL HUMAN RESOURCES DEVELOPMENT COUNCIL

OF SRI LANKA

ANNUAL REPORT

2019

Ministry of National Policies, Economic Affairs, Resettlement & Rehabilitation, Northern Province Development and Youth Affairs

354/2, NIPUNATHA PIYASA, 7TH FLOOR, ELVITIGALA MAWATHA, COLOMBO 05.

6. PROJECTS DONE BY PRIVATE SECTOR DIVISION IN 2019

6.1 FOREIGN TRAINING PROGRAMS FOR PUBLIC SECTOR OFFICIALS

Under the vision, “Our Workforce Future Ready” the National Human Resources Development Council of Sri Lanka has continued to organize more successful programs in the year 2019 for the Public Sector Officials and this year NHRDC was able to launch the first training programs in Philippines. The main objective of these programs is, to increase the Job-related competencies and individual growth of the public sector officials.

In 2019 NHRDC was able to organize three Training programs for different target groups such as Common public sector managerial staff, Higher Managerial Level Public Sector Officers and Engineers from Ceylon Electricity Board. The programs conducted are as follows:

6.1.1. Managerial Competency Development Program (MCDP)

The program targeted for Middle and Higher Public Sector Managerial Staff. This program was conducted with 3 days local session for each. The Local session resources persons were Mr. Ranil Sugathadasa, Dr. Kasun Nandapala and Mr. Chameera Udawatta. Details of the three programs are given below:

MCDP III

Number of Participants – 27

The Local Session of the program was held from 27th of Feb. to 1st of March and the Foreign Session was held on 10th March to 16th March 2019

Countries: Malaysia and Singapore.

17

Managerial Competency Development Program (Session I)
Agenda

Wednesday, July 19, 2018

Eng. Ranil Sugathadasa

9.00 am	Motivation for self development. Empowering Body, Mind, Heart and Spirit
10.30 am	Tea Break
10.45 am	Positive Attitude development, Self Awareness exploring the best version of the self and team
12.00 noon	Self Awareness and incremental development
1.00 pm	Lunch Break
2.00 pm	Self and team transformation with power of little bit, gratitude and 100 percent responsibility
3.00 pm	Tea Break
3.15 pm	Effective Decision Making
4.30 pm	End

Thursday, July 20, 2018

Prof. (Eng) Rangika Halwatura and Dr Kasun Nandapala, Arch. Chameera Udawatte

9.00 am	Project Time, Cost, Quality Management
10.30 am	Tea Break
10.45 am	Microsoft Project Application
1.00 pm	Lunch Break
2.00 pm	Microsoft Project Application
4.30 pm	End

Friday, July 21, 2018

Eng. Ranil Sugathadasa

9.00 am	Leadership in practice
10.30 am	Tea Break
10.45 am	Effective communication & Presentation skills
1.00 pm	Lunch Break
2.00 pm	Project Scope and Project HR Management
3.00 pm	Tea Break
3.15 pm	Project Risk, and Project Communication Management
4.30 pm	End

1.2

Teaching Load

1.2(1)

Teaching Load - Academic year 2017/2018

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Points are not claimed under this

section

1.2(2)

Teaching Load - Academic year 2018/2019

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Points are not claimed under this

section

1.2(3)

Teaching Load - Academic year 2019/2020

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Points are not claimed under this

section

1.2(4)

Teaching Load - Academic year 2020/2021

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Points are not claimed under this

section

1.2(5)

Teaching Load - Academic year 2021/2022

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Points are not claimed under this

section

1.2(6)

Teaching Load - Academic year 2022/2023

Please Refer the Next Page

Points are not claimed under this section

1.2(7)

Teaching Load - Academic year 2023/2024

Please Refer the Next Page

Points are not claimed under this

section

1.2(8)

Teaching Load - Academic year 2024/2025

Please Refer the Next Page

Points are not claimed under this

section

1.3

Preparation of Teaching Material

1.3.1

Preparation of lesson materials for distribution to students

1.3.1(1)

Lecture Notes and Slides

Please Refer the Next Page

Points are not claimed under this

section

1.3.2

Preparation of audio/video programmes /Computer Software for teaching

1.3.2(1)

Lecture Notes and Slides

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Points are not claimed under this

section

1.4

Teaching/Professional Experience

1.4.1

Service after being promoted as Lecturer, or service in equivalent teaching position or relevant professional experience in other organizations

1.4.1(1)

Service in the Post of Lecturer : from 1st October 2017 - 31st March 2019

Please Refer the Next Page

වෘත්තීය තාක්ෂණ විශ්වවිද්‍යාලය
வாழ்க்கைத்தொழில்சார் தொழில்நுட்பவியல் பல்கலைக்கழகம்
University of Vocational Technology
UNIVOTEC
100, කඳවල, රත්මලාන. இல.100, கந்தவல, இரத்மலானை. No. 100, Kandawala, Ratmalana. Sri Lanka.

My No: UoVT/AC/MPKCN

12.09.2017

Dr. M.P.K.C. Nandapala,
96,Eriyagoda Estate,
Pallawa – Dampitiya Road,
Hanhamunawa,Maspotha.

Dear Dr. Nandapala,

APPOINTMENT TO THE POST OF LECTURER

I have the honour to inform you that, upon the pending approval of the Board of Governors of the University of Vocational Technology in terms of the powers vested in it by paragraph (l) of section 05 of the University of Vocational Technology Act No.31 of 2008, to appoint you to the post of Lecturer in Construction Technology, with effect from 02nd October, 2017. This appointment will take effect from the date on which you will assume duties.

1. This appointment is subject to review by the University Appeals Board in terms of the section 36 (1) of the aforesaid Act.

2. This post is permanent. Unless your appointment is terminated earlier, you will be on probationary period of three (3) years from the date of assumption of duties and until such time you receive a letter confirming your appointment.

3. If your service is not up to the satisfactory level of the University, your probationary period can be extended by the Board of Governors as per part VII, 31 (1) of University of Vocational Technology Act No.31 of 2008.

4. Your service can be terminated at any time during the probationary period without assigning any reason whatsoever.

5. You are required to give three (3) calendar months' notice for resignation. In the event of your resigning or leaving the services of the University without giving the required notice or before the expiration of three (3) calendar months from the date when you should have given notice, you are liable to pay to the University a sum of money equal to the full amount which you may have received as your salary for the three (3) months preceding the date of cessation of service.

6. You will be bound by the provisions of the University Act No.31 of 2008, and any Ordinances, Statutes, By-Laws, Regulations, Rules etc. made there under or to any orders or Laws that will be given or enacted by the Democratic Socialist Republic of Sri Lanka.

උප කුලපති துணைவேந்தர் Vice Chancellor Tel: 011 2630704 ශිෂ්‍ය සේවා කේන්ද්‍රය மாணவர் சேவைகள் நிலையம் Student Service Centre. Tel: 011 2630701
අධ්‍යක්ෂ ජනරාල් பணிப்பாளர் நாயகம் Director General Tel: 011 2630706 කාර්යාලය பொது அலுவலகம் General Office Tel: 011 2630700
web : www.univotec.ac.lk E-mail : univotec@univotec.ac.lk Fax : 011 2630705

7. This is a full time appointment and you should not accept any other paid employment without prior permission of the Vice Chancellor.

8. Please intimate to me, through the Dean, Faculty of Industrial and Vocational Technology the date on which you assumed duties.

9. You will be required to enter into an agreement with the University before assuming duties. A copy of the Agreement form is annexed hereto.

10. The post carries a Salary Scale of U- AC3 (III)-2016 Rs.53,235-10*1240-13*1520-8*2020-101,555/per month.

    As per provisions of 17/2016 circular dated 31.12.2015 the annual salary scales up to 2020 as follows,

    With effect from - 2017.01.01 Rs.47,871 – 5*1082 - 53,281 per month
    With effect from - 2018.01.01 Rs.54,299 – 5*1228- 60,439 per month
    With effect from - 2019.01.01 Rs.60,727 – 5*1374- 67,597 per month
    With effect from - 2020.01.01 Rs.67,155 – 5*1520- 74,755 per month

    You will be placed on the initial Salary step of Rs.47,871/per month with effect from the date of assumption of duties. You will also be entitled to any other allowances applicable to your post.

11. You will be required to contribute to the Employees' Provident Fund by means of monthly deductions from your salary an amount equal to eight (8%) per centum of your earnings. The University will in addition, out of its funds, contribute at the same time a sum equal to twelve (12%) per centum of your earnings to the Provident Fund.

12. Three per centum (3%) of your earnings will be contributed by the University to the Employees Trust Fund in terms of the Provisions of the Employees' Trust Fund Act No. 46 of 1980.

13. All Lecturers shall complete an Induction Training course (which includes Teaching/Learning Methodologies) within a period of one year from the date of first appointment if it had not been already completed. This is a pre-requisite for confirmation in the post.

14. You should submit a certificate of physical fitness from the National Hospital, Colombo, on the prescribed form. If you are not certified as physically fit to serve in any part of the Island, your appointment will be terminated. You should submit your certificate of physical fitness before assumption of duties or within one month from the date you assume duties. The University will not reimburse any expenses connected with this medical examination.

15. You are required to take an oath or to make affirmation of allegiance to the Democratic Socialist Republic of Sri Lanka, and also make affirmation/oath under the sixth amendment to the constitution immediately after you assume duties. Copies of the oath/affirmation forms are annexed.

Please acknowledge receipt of this letter of appointment and state whether you accept the post on the terms and conditions stated herein by signing the letter of acceptance given on the end of the page.

Yours truly,

Nilmini Diyabedanage
Director General

Signed by: Prof. G.L.D.Wickramasinghe
Vice Chancellor

Cc:

1. Vice Chancellor
2. Dean - Faculty of Industrial &Vocational Technology
3. Dean - Faculty of Training Technology
4. Director Finance
5. Director Media & Information Services
6. Director Admission, Accreditation and Quality Assurance
7. Auditor General
8. Internal Auditor
9. Personal File

LETTER OF ACCEPTANCE.

The Vice Chancellor,
University of Vocational Technology.

Through Dean , Faculty of ....

With reference to the Vice Chancellor's letter No .... dated.................... I accept the appointment with effect from .... on the terms and conditions specified in the letter of appointment.

....
Date

....
Signature

1.4.1(2)

Service in the Post of Senior Lecturer II : from 1st April 2019 to date

Please Refer the Next Page

වෘත්තීය තාක්ෂණ විශ්වවිද්‍යාලය
வாழ்க்கைத்தொழில்சார் தொழில்நுட்பவியல் பல்கலைக்கழகம்
University of Vocational Technology
100, කඳවල, රත්මලාන. இல.100, கந்தவல, இரத்மலானை. No. 100, Kandawala, Ratmalana. Sri Lanka.

My No: UOVT/AC/MPKCN/517 20.11.2019

Through – Dean – Faculty of Industrial & Vocational Technology 26/11

Dr. M P K C Nandapala
Lecturer

Dear Dr. Nandapala,

APPOINTMENT TO THE POST OF SENIOR LECTURER GRADE (II)

I have the honour to inform you that, upon the approval of the Board of Governors of the University of Vocational Technology in terms of the powers vested in it by paragraph (XXI) of section 19(2) of Part V of the University of Vocational Technology Act No.31 of 2008, to appoint you to the post of Senior Lecturer Grade II in Construction Technology & Resourse Management, with effect from 01st April, 2019. This appointment will take effect from the date on which you will assume duties.

1. This appointment is subject to review by the University Appeals Board in terms of the paragraph (1) (a) of section 36 of Part VIII of the aforesaid Act.
2. This post is permanent. Unless your appointment is terminated earlier, you will be on Probationary period of three(3) years from the date of assumption of duties and until such time you receive a letter confirming your appointment.
3. You are required to give three (3) calendar months' notice for resignation. In the event of your resigning or leaving the services of the University without giving the required notice or before the expiration of three (3) calendar months from the date when you should have given notice, you are liable to pay to the University a sum of money equal to the full amount which you may have received as your salary for the three (3) months preceding the date of cessation of service.
4. You will be bound by the provisions of the University Act No.31 of 2008, and any Ordinances, Statutes, By-Laws, Regulations, Rules etc. made there under or to any orders or Laws that will be given or enacted by the Democratic Socialist Republic of Sri Lanka.
5. This is a full time appointment and you should not accept any other paid employment without prior permission of the Vice Chancellor.
6. Please intimate to me, through the Dean, Faculty of Industrial & Vocational Technology the date on which you assumed duties.

උප කුලපති துணைவேந்தர் Vice Chancellor Tel: 011 2630704 සිසු සේවා කේන්ද්‍රය மாணவர் சேவைகள் நிலையம் Student Service Centre. Tel: 011 2630701
අධ්‍යක්ෂ ජනරාල් பணிப்பாளர் நாயகம் Director General Tel: 011 2630706 කාර්යාලය பொது அலுவலகம் General Office Tel: 011 2630700
web : www.univotec.ac.lk E-mail : univotec@univotec.ac.lk Fax : 011 2630705

7. The post carries a Salary Scale of U- AC 3 2016A - Rs.54,600-10*1335-13*1630-8*2170-106,500/per month. You will be placed on the initial Salary step of Rs.71,028/per month (the applicable salary point w.e.f. 01.01.2019 as per the provisions of the Salary Circular 17/2016) with effect from the date of assumption of duties. You will also be entitled to any other allowances applicable to your post.
8. You will be required to contribute to the Employees' Provident Fund by means of monthly deductions from your salary an amount equal to eight (8%) per centum of your earnings. The University will in addition, out of its funds, contribute at the same time a sum equal to twelve (12%) per centum of your earnings to the Provident Fund.
9. Three per centum (3%) of your earnings will be contributed by the University to the Employees Trust Fund in terms of the Provisions of the Employees' Trust Fund Act No. 46 of 1980.

Please acknowledge receipt of this letter of appointment and state whether you accept the post on the terms and conditions stated herein by signing the letter of acceptance given on the end of the page.

Yours truly,

Prof. G.L.D. Wickramasinghe
Vice Chancellor

Cc:

1. Director General
2. Dean - Faculty of Industrial &Vocational Technology
3. Dean - Faculty of Training Technology
4. Director Finance
5. Director Media & Information Services
6. Director Admission, Accreditation and Quality Assurance
7. Auditor General
8. Internal Auditor
9. Personal File

LETTER OF ACCEPTANCE

The Vice Chancellor,
University of Vocational Technology.

Through Dean , Faculty of ....

With reference to the Vice Chancellor's letter No .... dated......................... I accept the appointment with effect from .... on the terms and conditions specified in the letter of appointment.

....

Date Signature

1.4.2

PhD/equivalent or higher Degree

1.4.2(1)

Degree of Doctor of Philosophy

Please Refer the Next Page

UNIVERSITY OF MORATUWA, SRI LANKA

This is to certify that

Manamendra Patabendige Kasun Chinthaka Nandapala

having successfully completed the prescribed course of study
and the examinations of the
University of Moratuwa, Sri Lanka
was admitted to the Degree of

Doctor of Philosophy

on

01st December 2016

Witness our hands at a convocation holden in Colombo on
The Eleventh Day of October Two Thousand and Seventeen

Vice-Chancellor

25940

Registrar

1.5

Postgraduate Supervision

1.5(1)

Postgraduate Supervision

Please Refer the Next Page

Points are not claimed under this

section

1.6

Institutional Development

1.6(1)

Institutional Development

Please Refer the Next Page

Points are not claimed under this

section

Section 2

Research, Scholarship and Creative Work

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2.1

Publication in refereed journal based on research for a degree

2.1(1)

Kasun Nandapala and R.U. Halwatura, “Design of a durable roof slab insulation system for tropical climatic conditions”, Cogent Engineering, vol.3,p.1196526,Dec.2016 (3*0.75)

Please Refer the Next Page

Nandapala & Halwatura, *Cogent Engineering* (2016), 3: 1196526
http://dx.doi.org/10.1080/23311916.2016.1196526

cogent engineering

CIVIL & ENVIRONMENTAL ENGINEERING | RESEARCH ARTICLE

Design of a durable roof slab insulation system for tropical climatic conditions

Kasun Nandapala[1*] and Rangika Halwatura[1]

Received: 19 February 2016
Accepted: 26 May 2016
First Published: 31 May 2016

*Corresponding author: Kasun Nandapala, Department of Civil Engineering, University of Moratuwa, Moratuwa, Sri Lanka
E-mails: mpkcnandapala@gmail.com, kasuncn@uom.lk

Reviewing editor:
Raja Rizwan Hussain, King Saud University, Saudi Arabia

Additional information is available at the end of the article

Abstract: Flat roof slabs become popular day-by-day due to the advantages like cyclonic resistance, the possibility of future vertical extension, and the possibility of utilizing as an additional working space. However, a serious matter of concern is its thermal discomfort, for which air conditioning is used as the most common remedy. This has led to extensive use of energy, increasing the operational cost of the buildings, and contributing to global warming. Hence, the current trend is to go for passive techniques. Insulating roof slabs is identified as a better passive way to make buildings thermally comfortable. In this study, several existing roof slab insulation systems and their performances were investigated, and the most effective system for tropical climates was identified. Since that system had an issue in durability, a new system was developed with a discontinued-stripped supporting arrangement, which withstood a 4MT-point load. Further, it was proven by comparing literature that the newly designed system has a heat gain reduction of more than 75%.

Subjects: Built Environment; Engineering & Technology; Sustainable Development

Keywords: roof slabs; insulation; thermal performance; structural performance; durability

1. Introduction

It is evident that deforestation in the world has reached an intolerable level and has become the primary cause for the imbalance that the world is facing today. This phenomenon has aggravated mainly because of the unplanned construction and the extensive land consumption caused due to the

ABOUT THE AUTHORS

Kasun Nandapala is a full-time PhD candidate at the Department of Civil Engineering in University of Moratuwa, who is carrying out his core research on thermal insulation in roof slabs. Rangika Halwatura is a senior lecturer at the Department of Civil Engineering in University of Moratuwa. The research interests of this team include but not limited to thermal optimization of buildings, development of sustainable construction materials, invention of techniques to promote sustainable built environment.

PUBLIC INTEREST STATEMENT

Global warming and the associated climate change are the biggest issues that the current world is facing. Consequently, the natural disasters have increased in intensity and severity. Therefore, structures need to be made robust, for which the use of flat concrete roof slabs is a good strategy. It provides some additional advantages like possibility of future vertical extension and possibility of using as a working space. However, the thermal discomfort in the immediate underneath floor is its major drawback. Even though air conditioning solves the problem, it is at a higher cost in the form of energy consumption. Insulating slabs is a better strategy to prevent this. In this study, a roof slab insulation has been developed which is structurally sound and durable. It was proven that this system reduces more than 75% heat gain into a building, which eventually will either eliminate the necessity of air conditioning or will reduce the necessary capacity.

Nandapala & Halwatura, *Cogent Engineering* (2016), 3: 1196526
http://dx.doi.org/10.1080/23311916.2016.1196526

cogent • engineering

increased population. Consequently, due to the scarcity created, "land" has become one of the most expensive commodities, particularly in urban areas. In this context, multi-storey construction has become popular, as it produces a higher floor-area ratio (Dareeju, Meegahage, & Halwatura, 2011).

Consequently, use of flat concrete roof slabs has begun to be popular as it provides the flexibility of using either as a working space, as a rooftop garden or as a temporary shelter till a future vertical extension is taken place (Banting, 2005; Berardi, GhaffarianHoseini, & GhaffarianHoseini, 2014; Halwatura & Jayasinghe, 2007). Further, roof slabs increase the robustness of the structures and provide an additional cyclonic resistance which is very handy against the climate change taking place in the world (Halwatura, 2013).

However, the use of roof slabs has not been sufficiently penetrated to the middle-class population due to a variety of reasons. Thermal discomfort in the immediate underneath floor has been found to be the primary reason for that (Nandapala & Halwatura, 2014). The concrete roof slabs get heated in the daytime and emit long-wave radiation to the underneath space, causing the discomfort (Halwatura & Jayasinghe, 2008).

Air conditioning is the most common remedy to overcome this issue. Even though air conditioning resolves this issue, a higher operational cost has to be incurred. Further, this increases the energy usage which leads to the biggest problem in the world, Global Warming (Halawa et al., 2014; Lean & Rind, 2001; Macilwain, 2000).

Elaborating the impact of this in quantitative terms, in Singapore, buildings use up to 57% of the total energy usage of the country (Kwong, Adam, & Sahari, 2014). In Malaysia, a country with similar tropical climatic conditions, more than 30% of the total energy in buildings is used for making them thermally comfortable (Dong, Lee, & Sapar, 2005). Those findings sum up that around 15–20% of the total energy usage in tropical countries is used for enhancing thermal comfort in buildings. It is evident that the amount of energy used for comfort is much more than what the world can afford.

Hence, active cooling (in the form of Air Conditioning) is not a preferred remedy to achieve thermal comfort. Therefore, passive cooling techniques have emerged (Al-Obaidi, Ismail, & Abdul Rahman, 2014; Alvarado, Terrell, & Johnson, 2009; Sadineni, Madala, & Boehm, 2011), insulation in particular (Al-Homoud, 2005; Brito Filho & Santos, 2014; Dylewski & Adamczyk, 2014). Insulating the roof has been identified to be the best option as it is the element that contributes to about 70% of the total heat gain inside buildings (Halwatura, 2014; Vijaykumar, Srinivasan, & Dhandapani, 2007).

There are several roof slab insulation techniques tried out in the world. A research work carried out in Florida, USA, has obtained a 38% energy saving by applying a cool paint (Parker & Barkaszi, 1997), and another study in Italy, with the same technique, has achieved a 54% energy saving (Romeo & Zinzi, 2013). A daily heat gain reduction of 56% has been observed in Greece, using a 60 mm ventilated air gap as an insulator (Dimoudi, Androutsopoulos, & Lykoudis, 2006). A system developed in Sri Lanka, a tropical country, has achieved a heat reduction of 75% using a 25 mm polystyrene layer (Halwatura & Jayasinghe, 2008). Some laboratory experiments have obtained similar results as well (Alvarado & Martínez, 2008; Megri, Achard, & Haghighat, 1998).

Above figures incontrovertibly suggest that insulation can be effective in any climatic condition. Since this study focuses on tropics, the system developed in Sri Lanka was identified to be the most recent and the most effective to suit the conditions.

A further study on the system suggested that this particular system has been developed as an alternative to one of the most common insulation systems used in tropical countries, shown in Figure 1. It has an insulation layer on the structural slab and a protective screed on top of it.

Nandapala & Halwatura, *Cogent Engineering* (2016), 3: 1196526
http://dx.doi.org/10.1080/23311916.2016.1196526

cogent • engineering

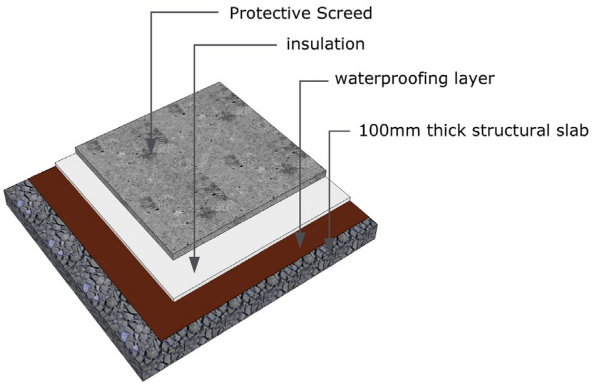

Figure 1. The most common roof insulation system used in tropical countries.

This system had been tested under practical conditions and its thermal performance is emphasized. However, this has imposed a restriction on loading, since a layer of weak material (insulation material) is placed between two layers of concrete, and the load path from the slab passes through it.

The system by Halwatura and Jayasinghe (shown in Figure 2) has been developed as a remedy for this. It has a set of concrete strips within the insulation layer to support the top screed. Hence, the load path passes through those strips, without transferring the load to the insulation layer. Further, a 50 mm × 50 mm steel mesh has been introduced to distribute the load.

However, a field study suggested that there is a concern about the durability of the system as some water patches were observed in slab soffits in the long run. A thorough study resulted in finding that water was stagnant in the polystyrene layer. This phenomenon can further be elaborated as follows:

The arrangement of supporting strips in plan view is shown in Figure 3. It is apparent that there is no drainage path for the penetrated water to flow out, as the insulation material is enclosed by a set of continuous concrete strips. Hence, a water head is developed in the system, resulting in a reduction in the lifespan of the waterproofing layer.

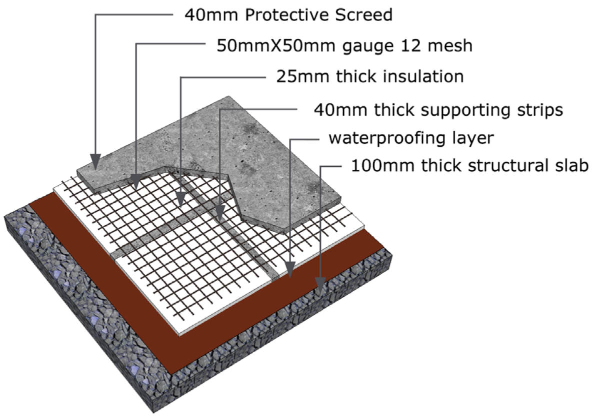

Figure 2. The insulation system with continuous concrete strips by Halwatura and Jayasinghe (2008).

Nandapala & Halwatura, *Cogent Engineering* (2016), 3: 1196526
http://dx.doi.org/10.1080/23311916.2016.1196526

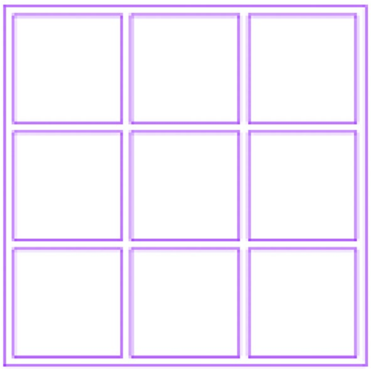

Figure 3. Plan view of the supporting arrangement of the system with continuous concrete strips.

2. Objectives

The primary goal of this study is to develop a new system that is structurally sound with a proper drainage path. The objectives of this study are as enlisted below:

- To investigate the importance of roof slab insulation and performance of existing techniques It was expected to study the importance of roof slab insulation in general, importance of it in tropical climates, existing techniques, their advantages and disadvantages by means of a literature survey. (This was presented in Section 1).
- To develop a new system that is structurally sound with an optimum structural arrangement The structural arrangement was optimized in such a way that it has no restriction for loading. Further, a proper drainage path was provided for the penetrated water to flow out. Most importantly, the thermal performance of the system was studied as well.

3. Methodology

3.1. Overall methodology

A literature survey was carried out to figure out the significance of roof slab insulation in tropical climates, the existing techniques, and their strengths and weaknesses.

A field study was carried out to check and verify the data in literature and to find out the practical issues of those techniques in the operational stage.

Finite element modeling by SAP 2000 software (verified by manual calculations) was used to optimize the structural arrangement. The procedure followed in this optimization process is described in Section 3.2.

Then, actual scale testing was performed to verify the data obtained by computer simulations.

Finally, the possible thermal gain reduction is predicted based on the results of a similar technique in literature.

3.2. The method followed to optimize the strip arrangement

It was decided to provide a proper drainage path along the insulation layer, as it was the major drawback identified in the system with continuous concrete strips. First of the options considered was to remove the supporting concrete strips in one direction, of which a typical plan view is shown in Figure 4. The objective of providing a support was to eliminate the restriction for loading. Hence, the system had to be designed in such a way that it can withstand any practical load applied on that. Therefore, a structural analysis was carried out assuming that the imposed load applied on the system is 5 kN/m^2, which is the maximum specified in BS 6399-1: 1996 (British Standards Institution, 1996).

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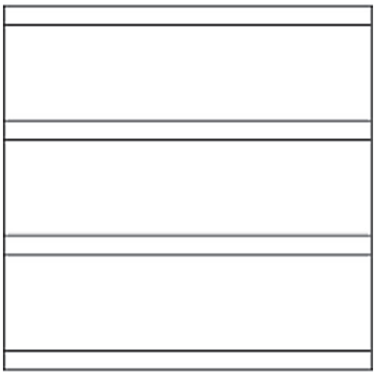
Figure 4. Plan view of the supporting arrangement after removing strips in one direction.



In this context, there were four variables to be considered:

(1) Spacing between strips
(2) Size of the strips
(3) Strength and the mix proportion of the concrete to be used
(4) Reinforcing arrangement in the protective screedAn optimum spacing for the system was to be found out. Because the system would have structurally failed if the strips are placed too far apart to each other, and the thermal performance of the system would have depleted, if they were placed too closer to each other as it increases the concrete area within the insulation layer.

It was intended to optimize the system by minimizing the concrete area within the insulation. Hence, a minimum size of the strips that would bear the load applied on that had to be determined.

The concrete used had to be strong enough to carry the load, and had to be able to be compacted in an area of a width of 40 mm. Hence, concrete with a lower maximum aggregate size (chip concrete) was used. A suitable proportioning was found out by laboratory experiments.

The protective screed had to be designed as a load bearing slab itself. Since concrete is a material which is weak in tension, some arrangement of reinforcement had to be incorporated into the system (Min, Yao, & Jiang, 2014). The bottom reinforcement was fixed to be a 50 mm × 50 mm gauge 12 mesh, due to the convenience of construction. Four options were considered for the top reinforcing arrangement: no reinforcement, 6 mm mild steel bars near supports, 10 mm tor steel bars near supports, and a similar continuous 50 mm × 50 mm mesh (double nets). Then the optimum arrangement was found by computer simulations.

Thereafter, the system was further optimized by varying the spacing between strips while discontinuing them. A typical arrangement of this case is shown in Figure 5. In this case, three more variables were added;

(1) Spacing between strips (Number 1 in Figure 5)
(2) Longitudinal spacing between supports (Number 2 in Figure 5)
(3) Length of the supports (Number 3 in Figure 5)

Different finite element models were developed by varying the spacing of strips, and the optimum arrangement for each value of spacing was found out. This process went on until the top screed becomes a flat slab with a set of blocks as supports.

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Figure 5. Variables to be considered in optimizing the strips in longitudinal direction.

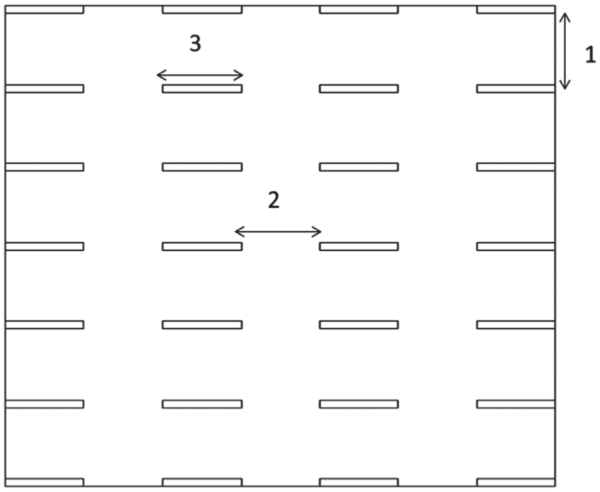
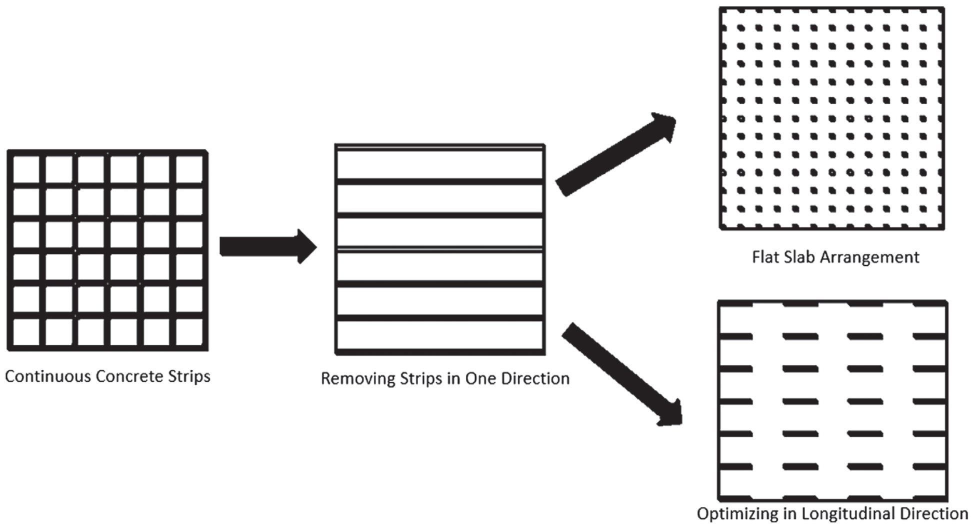


Figure 6. The process followed to optimize the system.



Then the system with a minimum concrete area within the insulation layer was selected as the best arrangement.

A graphical elaboration on the process followed to optimize the system is depicted in Figure 6.

4. Results

4.1. Step 1: Removing strips in one direction

Initially, the size of strips was fixed to 50 mm, and a concrete strength of 15 N/mm^2 was assumed for initial trial calculations. Then, the system was analyzed for different values of spacing, and the bearable loadings were calculated for each spacing, and each reinforcing arrangement by a reverse calculation of the procedure explained in BS 8110 part 1:1997 (British Standards Institution, 1997). A typical model developed by SAP 2000 software (the model developed for the arrangement shown in Figure 3) is shown in Figure 7.

Figure 8 shows the results obtained by computer simulations (Only hogging bending moment is shown here as it was the critical parameter). It shows the moment capacities for different top

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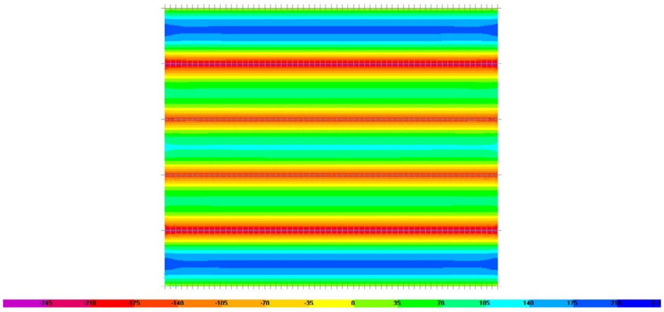

Figure 7. A typical model obtained by computer simulations with strips only in one direction.

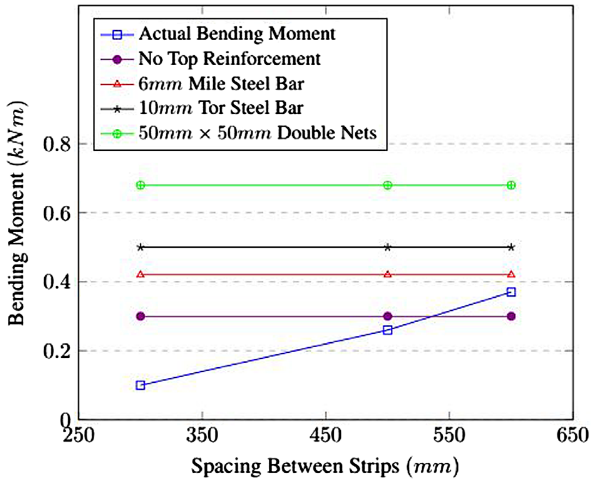

Figure 8. Actual bending moments and moment capacities of different reinforcing arrangements when the strips in one direction are removed.

reinforcing arrangements described in Section 3, and the actual bending moments for different strip-spacings.

Those results suggest that any form of the selected top reinforcement can satisfy the moment resistance required. However, the strips should be spaced in less than 540 mm if no top reinforcement is provided.

This last option was selected for further analysis due to the convenience in construction.

4.2. Step 2: Discontinuing the strips

As it has been mentioned in Section 3, the next step was to find out the optimum arrangements by varying the spacing between strips. A set of computer models were developed for various options of strip-spacing (number 1 in Figure 5), spacing between supports (number 2 in Figure 5) and length of the supports (number 3 in Figure 5). The optimum arrangements obtained for three different values of strip-spacings are presented in Table 1.

Table 1. The optimum arrangements obtained for different values of strip-spacing

Spacing between strips (mm) ("1" in Figure 5)	Spacing between supports (mm) ("2" in Figure 5)	Length of the supports (mm) ("3" in Figure 5)
300	400	300
400	300	300
500	100	200

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4.3. Flat slab arrangement

The next option was to minimize the size of the supports and to support the system by a set of blocks. In this case, the protective screed layer behaves as a flat slab. Figure 9 shows the actual bending moments and the moment capacities for different block-spacings with a 50 mm × 50 mm gauge 12 mesh as reinforcement.

The results suggest that it is possible to achieve the required structural capacity, if the blocks are spaced at 150 mm or less in both directions.

4.4. Step 4: Selecting a suitable width of the strips/supports

Since the height of the supporting strips is small in comparison with its cross-sectional area, the buckling failure was ruled out. Hence, the minimum width required was calculated by a compressive strength calculation. The results obtained are shown in Table 2.

Results show that a minute width is sufficient to carry the load. However, a minimum width of 25 mm is selected owing to the practicality of construction.

4.5. Step 5: Selecting the best system

The next step was to single out a system out of the four options short-listed (shown in Table 3). Since the intention is to optimize the system, it was intended to minimize the concrete are in the layer, since concrete increases the composite conductivity of the layer as it is not an insulation material.

Figure 9. Bending moments and moment capacities of the protective screed with a 50 mm × 50 mm gauge 12 Mesh for a flat slab arrangement with different support spacings.

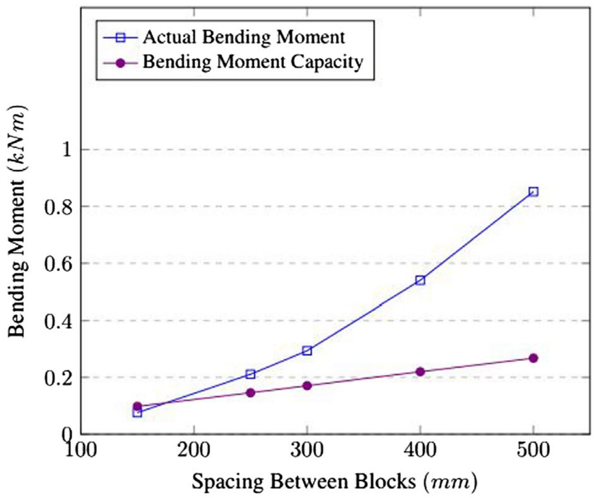

Table 2. Calculations for finding minimum width of strips

Calculation	300 mm spacing between strips	400 mm spacing between strips	500 mm spacing between strips	Flat slab arrangement
Effective area (m^2)	0.21	0.24	0.15	0.04
Dead load (kN)	0.21	0.24	0.15	0.04
Live load (kN)	1.05	1.20	0.75	0.20
Design load (kN)	1.97	2.26	1.41	0.38
Minimum area of support (mm^2)	131	150	94	25
Minimum required width (mm)	0.44	0.50	0.47	5.00

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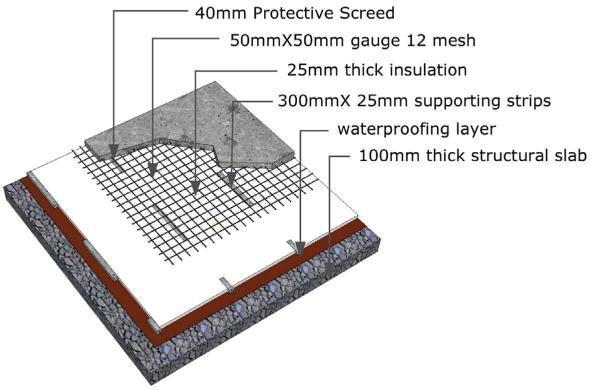
Figure 10. Isometric view of the derived system.



The concrete/total area ratio of the existing system is shown in Table 3 for comparison purpose. It clearly shows that all the systems selected have a much lower concrete area than the existing system. The system with the lowest concrete area (the system with 400 mm strip-spacing) was selected as the best system. An isometric view of this system is shown in Figure 10.

4.6. Step 6: Selecting a suitable concrete mix

The other variable fixed in Section 3 was the mix proportion of the concrete used. Since the supporting strips of the selected system are only 25 mm thick, it was necessary to specify a lower maximum aggregate size for the concrete. As chipped metal (with a maximum size of 10 mm) is a common construction material, a mix design was performed to achieve the assumed strength of 15 N/mm^2. Several options were considered by varying the Water–Cement ratio from 0.6 - 0.8.

All the tested mixes gained the required strength of 15 N/mm^2. Hence, the mix tried out for a water–cement ratio of 0.7, with 1:2:3 volume proportion of cement, sand and metal respectively was selected as the suitable mix proportion due to the convenience of specifying in practice.

4.7. Physical model testing

The next step was to check the strength of the system by physical model testing. The system was loaded with a calibrated proving ring to measure the applied load, and the deflection was measured with a dial gauge. The experimental setup used is shown in Figure 11. Both the readings were continuously taken down till the system failed. The obtained load-deflection curve is shown in Figure 12.

The graph in Figure 12 shows that the system can be loaded up to about 30 kN without cracking, and the system can be loaded up to 37 kN (approximately 4MT) without failing structurally. This value is higher than any practical load specified in BS 6399-1: 1996 (British Standards Institution, 1996). Therefore, it is proven that this system is structurally sound.

Table 3. Calculations for finding minimum width of strips

Calculation	300 mm Spacing	400 mm Spacing	500 mm Spacing	Flat slab	Existing system (Halwatura & Jayasinghe, 2008)
Concrete area (m^2)	3.71	3.51	3.57	5.61	16.16
Total area (m^2)	97.5	105.5	101.5	99.0	100.8
Concrete ratio	3.8%	3.3%	3.5%	5.7%	16.0%

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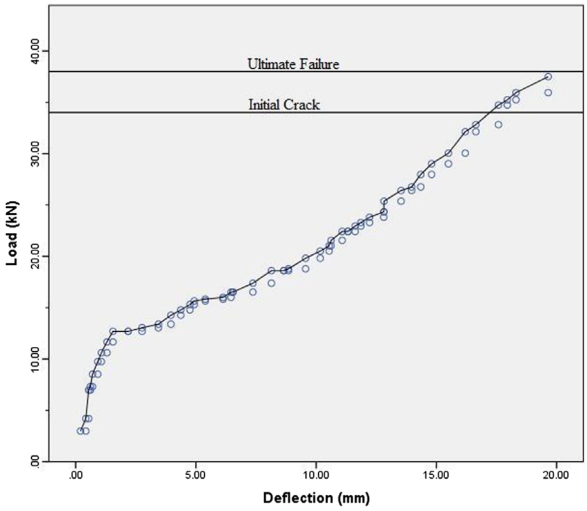
Figure 11. Experimental setup of the actual scale testing.

Figure 12. The graph of load vs. deflection obtained by actual scale testing.



Even though the deflection showed higher values, it was observed that the top screed sags independently without affecting the structural slab. Hence, it was not considered as a serviceability failure of the system.

5. Discussion

The necessity of a supporting arrangement for the top screed was to make the insulation system structurally sound, eliminating the restriction for loading the roof slab. The system designed addressing that issue had a durability issue since a drainage path was not provided for the penetrated water. The major aim of developing a new system was to address those two issues.

The actual scale testing in Section 4.7 proved that it is structurally sound, by withstanding a 4 MT point load on the system. Since the supporting strips are discontinued, a drainage path is provided within the insulation layer, addressing the issue of durability.

However, since this is a thermal insulation system, it is necessary to compare the thermal performance of the system with existing techniques.

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Table 4. Comparison of thermal conductivities of the new system and the existing system

System	Composite conductivity of the insulation layer ($Wm^{-1}K^{-1}$)	Composite conductivity of the system ($Wm^{-2}K^{-1}$)
The existing system (Halwatura & Jayasinghe, 2008)	0.039	1.1
Newly designed system	0.034	1.0

An adjustment for thermal conductivity values was necessary to be made since the insulation layer consists of a set of concrete supports within the insulation layer. The adjustment was made according to Equation (1) (Progelhof, Throne, & Ruetsch, 1976).

$$\frac{1}{K_I} = \frac{1-\phi}{K_p} + \frac{\phi}{K_c} \tag{1}$$

where K_I is the thermal conductivity of the composite insulation layer ($\mathrm{Wm}^{-1}\ \mathrm{K}^{-1}$); K_p is the thermal conductivity of the insulation material – polystyrene ($\mathrm{Wm}^{-1}\ \mathrm{K}^{-1}$); K_c is the thermal conductivity of concrete ($\mathrm{Wm}^{-1}\ \mathrm{K}^{-1}$); ϕ is the volume fraction of concrete.

A comparison of the conductivity values between the newly designed system and the system by Halwatura and Jayasinghe is shown in Table 4 (Please see Appendix A for detailed calculations). It shows a 9% reduction of heat transfer in the new system.

The system by Halwatura and Jayasinghe has proven to achieve a 75% heat reduction into the buildings (Halwatura & Jayasinghe, 2008). Table 4 shows that the newly designed system has a lower thermal conductivity. Hence, the newly designed system should theoretically have a heat gain reduction of more than 75%.

A few limitations of this study can be identified. First, the optimization technique used is simple as it is performed by varying the structural arrangement and mix proportions. A further optimization may be performed by replacing the materials with newly invented, more effective materials, either as the insulator or as a structural element.

In this study, the thickness of the insulation material was taken to be 25 mm. Thus, the only mode of failure of the supporting strips considered was crushing. However, if a researcher intends to vary the thickness of the insulation, other modes of failure like buckling should be considered depending on the thickness considered.

6. Conclusions

Roof slab insulation is very significant to mitigate and adapt to global warming. Developing an insulation system that is thermally effective, structurally sound and durable was the main objective of this study. A system that contains an insulation layer on top of the structural slab and a protective screed on top of it, which is supported by a set of discontinuous concrete strips was selected as the option to develop. The discontinuity of the strips provides a drainage path, making the system more durable in comparison with similar existing techniques, while the concrete strips provide the structural stability. The optimization was performed by finite element modeling. It was found out that a set of 300 mm × 25 mm strips in 300 mm longitudinal clear spacing and 400 mm transverse spacing cast by 1:2:3 chip-concrete with a water–cement ratio of 0.7 can withstand an imposed load of 5 kN/m^2, which is the maximum specified for a roof. An actual scale physical model withstood a 4MT-point load, emphasizing that the system is structurally sound. A calculation of composite conductivities and a comparison with an existing system has proven that this system can reduce the heat gain into a building by more than 75%.

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Appendix A

Calculating thermal conductivity of the insulation layer

For the Newly Designed System, (The assumed thermal conductivities are shown in Table A1)

Table A1. Thermal conductivities of the materials used

Material	Thermal conductivity (Halwatura & Jayasinghe, 2007)
Concrete	1.7 $W/m^{-1}K^{-1}$
Polystyrene	0.033 $W/m^{-1}K^{-1}$

$$\frac{1}{K_I} = \frac{1-\phi}{K_p} + \frac{\phi}{K_c}$$
$$= \frac{1-3.3\%}{0.033} + \frac{3.3\%}{1.7}; \quad (\phi = 3.3\% \text{ by Table 3})$$
$$K_I = 0.034Wm^{-1}K^{-1}$$

For the Existing System,

$$\frac{1}{K_I} = \frac{1-\phi}{K_p} + \frac{\phi}{K_c}$$
$$= \frac{1-16\%}{0.033} + \frac{16\%}{1.7}; \quad (\phi = 16\% \text{ by Table 3})$$
$$K_I = 0.039Wm^{-1}K^{-1}$$

Calculating thermal conductivities of the systems themselves

Table A2. Surface resistances of roof slab (Halwatura & Jayasinghe, 2008)

Location	Symbol	Surface resistance
Top surface	R_T	0.04
Soffit	R_S	0.14
Insulation system	R_I	(calculated above)

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$$\text{Thermal Resistance of the New System} = \frac{T_1}{K_1} + \frac{T_2}{K_2} + \frac{T_3}{K_3};\ (T_i - \text{ Thickness of the layer})$$
$$= \frac{0.04}{1.7} + \frac{0.025}{0.034} + \frac{0.1}{1.7}$$
$$= 0.82m^2KW^{-1}$$

$$\text{Air-to-Air Resistance of the New System} = R_T + R_I + R_S$$
$$= 0.04 + 0.82 + 0.14$$
$$= 1.0m^2KW^{-1}$$

$$\textbf{Hence, the Composite Conductivity of the newly designed system} = \frac{1}{1.0}$$
$$= 1.0Wm^{-2}K{-}1$$

$$\text{Thermal Resistance of the Existing System} = \frac{T_1}{K_1} + \frac{T_2}{K_2} + \frac{T_3}{K_3}$$
$$= \frac{0.04}{1.7} + \frac{0.025}{0.039} + \frac{0.1}{1.7}$$
$$= 0.72m^2KW^{-1}$$

$$\text{Air-to-Air Resistance of the Existing System} = R_T + R_I + R_S$$
$$= 0.04 + 0.72 + 0.14$$
$$= 0.90m^2KW^{-1}$$

$$\textbf{Hence, the Composite Conductivity of the existing system} = \frac{1}{0.9}$$
$$= 1.1Wm^{-2}K{-}1$$

2.2

Other research publications in refereed journals

2.2(1)

Kasun Nandapala, Madujith Sagara Chandra, R.U. Halwatura, A study on the feasibility of a new roof slab insulation system in tropical climatic conditions, Energy and Buildings, 2019, 109653, ISSN 0378-7788, https://doi.org/10.1016/j.enbuild.2019.109653.

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A study on the feasibility of a new roof slab insulation system in tropical climatic conditions

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ABSTRACT

A roof slab provides an extra robustness and a cyclonic resistance to the structures due to its self-weight. However, its performance in warm humid conditions is unsatisfactory because of the thermal discomfort in the immediate space beneath. Insulation has been recognized as an effective passive approach to address this issue. Thus, numerous insulation systems have been developed throughout the world. In this study, a system proven to be fruitful in tropical conditions was chosen and its negative aspects were recognized. Then, a new insulation system (a system with discontinuous supporting strips) was developed addressing the key drawbacks, and its thermal performance was compared with the prevailing systems. Prototype testing indicated that the negative effect of the supporting strips on the thermal performance of the system is negligible. Further, it was proven that this system achieves a heat gain reduction of more than 75%. An actual scale physical model proved that the system performs even better than a Calicut-tiled roof with a timber ceiling in thermal aspects. Computer simulations deduced that on a sunny day in tropical conditions, about 20% of the peak cooling load reduction can be achieved by the system. In addition, it was found out that about 5% reduction of life cycle cost was achieved by this technique for a lifespan of 10–50 years. And also, it was proven that the insulated slab performs better than an insulated Calicut tiled roof in terms of Life Cycle Costing.

1. Introduction

It is forecasted by the research community that the intensity and the severity of the natural disasters will be increased due to the drastic climatic changes [1–3]. One of the vital natural disasters common in tropical countries is cyclones. Hence, it has made the designers in tropical countries to develop disaster-resistant structures [4,5].

Thus, a number of research works have been carried out to increase the robustness of the structures. It has been scientifically proven that flat roof slabs cater this demand due to its large self-weight [6]. Further, it provides some additional benefits like the possibility of future vertical extension, ability to use as an extra working space, and having vegetation on top. And also, it adds a significant economic value by regaining the land as well [7].

Despite these benefits, the use of flat concrete slabs is not very popular in tropical countries due to the lack of thermal comfort [8]. When a concrete slab gets heated due to the direct exposure to the sunlight, the longwave radiation makes the immediate space beneath thermally uncomfortable. The effect is worse at the day time with a significant effect during the night as well [7]. Air conditioning the affected area is the most common remedy, which is unfavourable in both economic and environmental aspects.

Nonetheless, a significantly higher portion of commercial buildings is air-conditioned. Consequently, around 20% of total energy demand of tropical countries is for making thermally comfortable building interiors [8]. This high consumption of energy must be discouraged as it directly contributes to the energy crisis [4,6–11].

Subsequently, the research community has come up with some feasible solutions in the form of passive techniques. They are a set of techniques that the designers incorporate during the design phase itself so that the buildings operate with minimum operational energy [12–15]. Insulating the building envelope is one such popular technique. Even though this incorporates an additional initial investment, that cost is proven to be paid back by

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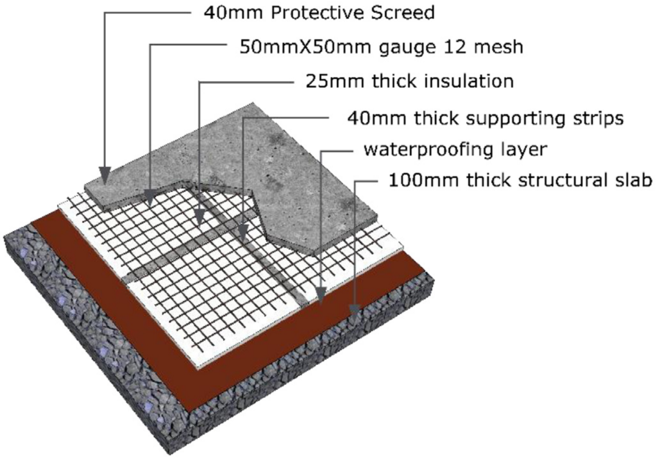

Fig. 1. Halwatura and Jayasinghe slab insulation system with a continuous strip arrangement [41.].

the reduction in operational cost within a reasonable span of time [16–20].

Thermal insulation of the roof is in the focus of the research community as it contributes to about 70% of the total heat gain of buildings [21]. There are several techniques used in roof thermal insulation, such as applying a cool paint [15,22–26], using a variety of insulation materials in roofing [27–35], and using rooftop vegetation [36–40]. All the above systems have been proven to perform well with regard to thermal aspects. But, when it comes to roof slabs, both thermal performance and structural integrity of the system have to be concerned.

A study by Halwatura and Jayasinghe has presented the structural integrity of a thermally insulated roof slab in addition to thermal performance. Details of the system are as shown in Fig. 1 [41].

After several years, another study by Nandapala and Halwatura has optimized the system in terms of structural aspects and has come up with a discontinuous strip arrangement to enhance the structural integrity of the system. Details of the novel system are as shown in Fig. 2 [42]. This study states that it has addressed a durability issue associated with the previous system by providing a set of drainage paths within the insulation. Newly introduced drainage paths are as shown in Fig. 3. It has further proven that this system has the capacity of withstanding any practical load on a roof [42,43].

However, the thermal performance of the system by Nandapala and Halwatura has not been studied comprehensively. This paper

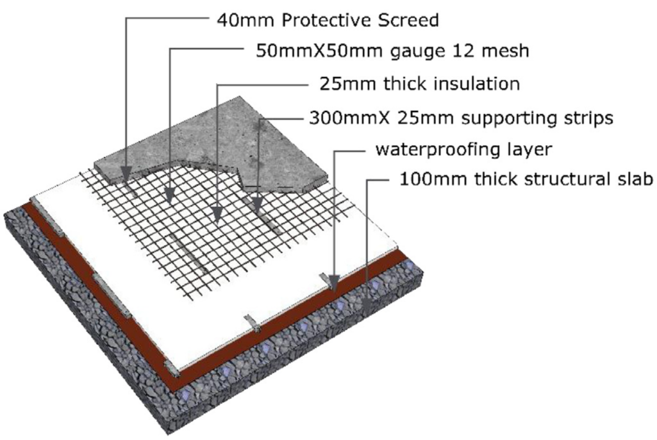

Fig. 2. The newly designed system with discontinuous supporting strips [42].

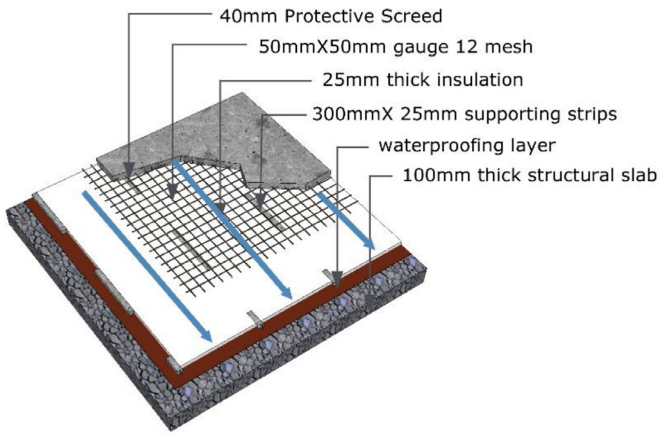

Fig. 3. Drainage paths of the newly designed system.

is intended to address that gap. Further, the peak cooling reduction and the financial feasibility of the system are presented here.

2. Objectives

2.1. Overall objective

The main objective of the article is to access the effectiveness and feasibility of the newly designed roof slab insulation system in tropical conditions.

2.2. Specific objectives

The specific objectives of this study are as listed below;

- To compare the thermal performance of the newly designed roof slab insulation system with similar existing techniques
- To compare the thermal performance of the system with an insulated Calicut-tiled roof
- To investigate the peak cooling load reduction that can be achieved by the novel system
- To check the financial feasibility of the system in comparison with a traditional Calicut-tiled roof

3. Materials and experimental methods

3.1. Thermal performance comparison of the novel roof slab insulation system with prevailing techniques

Physical model testings which were done in 2018 were used to achieve this objective. Four prototype models, as shown in Fig. 4, were constructed to study the thermal performance of the newly developed discontinuously supported insulation system.

The specific details of four prototype models are as listed below

- A control experiment (a model without any insulation)
- A model with a continuous-strip supporting arrangement (Fig. 1) [41]
- A model with the discontinuous supporting arrangement (novel system) (Fig. 2) [42]
- A model without any supporting arrangement (continuous insulation layer)

Plan area of each prototype model was 1.2 m × 1.2 m and each was 1.0 m high. Since the scope was limited in roof slab insulation, each wall was kept uninsulated. There, the walls were constructed using half brick thick walls made of un-plastered engineering bricks (0.51 W/mK). And reinforced concrete (1.7 W/mK) was used in roof slabs.

Fig. 4. Prototype models constructed to compare the thermal performance.

125 mm thick uninsulated reinforced concrete slab was used in the control experiment. It was used to study the effect of insulation in general. The system by Halwatura and Jayasinghe was to compare the two insulation systems, and the continuously insulated system was used to study the reduction in effectiveness due to the concrete layers present in the insulation. A detailed description of strip arrangement is available in a previous publication of authors [42].

Temperature readings were taken at ten-minute intervals during five continuous typical sunny days until a consistent ambient temperature variation was obtained. Then the average temperature of each hour was calculated after removing the outliers. Later consistent temperature values for each hour were obtained. To have enhanced reliable outcomes, one common set of readings representing the thermal readings of five days was obtained using the figures with minimum standard deviations.

Slab top and slab soffit temperatures were used for comparison purpose to obtain the real effect of insulation, minimizing the effects of any local variations within the systems. The 'GL820 Midi Data Logger' was used to obtain temperatures for an uninterrupted set of readings. The recordings were graphically represented, and the time lags and the decrement factors of each system were calculated and the thermal performances of the systems were evaluated based on them.

3.2. Thermal performance comparison with an insulated Calicut tiled roof

Section 3.1 comprised a thermal performance comparison of the discontinuous stripped roof slab insulation system with a set of slab insulation systems. As discussed in Section 1, despite many advantages of the roof slabs, they are not much popular in the community. This is mainly due to thermal discomfort [8]. Hence, it is worthwhile to compare the degree of insulation with an insulated Calicut-tiled roof, which is the most popular in tropical conditions.

The physical model made to the actual scale used for testing is shown in Fig. 5a. The Calicut-tiled roof in the model was insulated with a 3 mm foil layer, an air gap between its timber ceiling and the roof covering. The uninsulated slab in the physical model was with 125 mm uninsulated RCC slab while the insulated slab was that of shown in Fig. 2. Here also GL820 Midi Data Logger was used to obtain temperature readings of rooftop and soffit surfaces.

Those temperature readings were logged with respect to an uninsulated slab, an insulated slab and a Calicut-tiled roof on the same side of the building to negate the different impacts in solar radiation with the time of the day. The top and soffit temperature readings were obtained in the same way described in Section 3.1, and the rooftop and soffit temperature variations were compared.

3.3. Accessing the peak cooling load reduction of the slab insulation system

A typical 15 m × 15 m office building was selected to assess the performance since previous literature is available for such a building. Since the objective was to analyse the effect of heat gain through the roof, other housing elements were included with as many passive features as possible. The external walls were taken to be 225 mm thick brick walls. No windows were placed in East and West walls, and the provided windows in North-South directions were coupled with 1 m overhangs to prevent direct solar radiation being penetrated in. The simulated model is shown in Fig. 6.

Calibrating the model is significant before extending it to predict the performance through simulation. In this case, the model shown in Fig. 5b was used as the basic model, of which the top surface and soffit temperatures had been logged over a period of 24 h. Then, a computer simulation was performed with the software package "Design Builder v4" and the internal and external variables such as thermal properties of materials, energy generation by equipment etc. were adjusted until the simulated model behaves similarly to the actual conditions. The top surface temperatures of the actual model and the simulation of the finally calibrated model is shown in Figs. 7 and 8 shows those results in the

Fig. 5. (a) The actual scale model used to compare the thermal performances of the Calicut-tiled roof and the insulated slab, (b) the virtual model developed for the actual scale model.

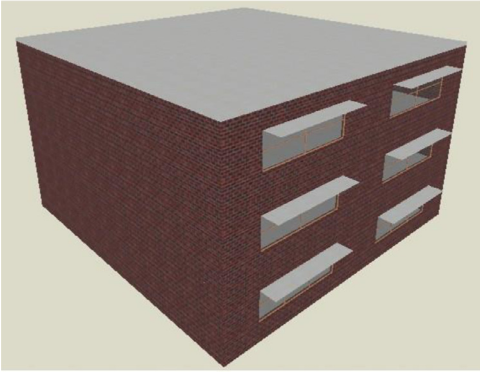

Fig. 6. The model used to perform computer simulations.

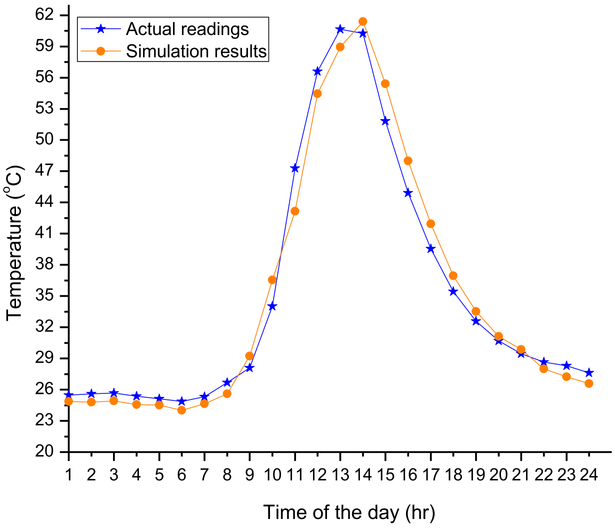

Fig. 7. Actual readings and the simulated results of the slab top in the calibrated model.

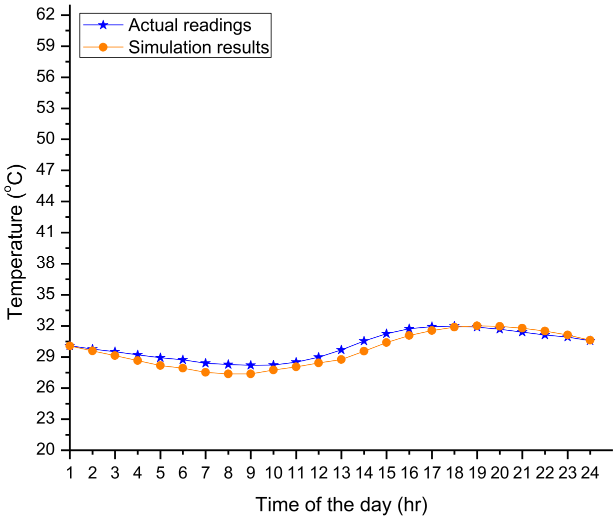

Fig. 8. Actual readings and the simulated results of slab soffit in the calibrated model.

soffit. Figs. 7 and 8 clearly indicated that the actual readings behave very similar to the simulation outcomes.

Typically, it is sufficient to match the actual indoor temperatures to them of the simulated model to obtain sufficiently accurate results. However, in this case, it was decided to use the surface temperatures of the slab to increase the accuracy of the model since it is the element under consideration. The other relevant details of the virtual model were as listed in Appendix A.

3.4. Accessing the financial feasibility of the slab insulation system

Finally, the results obtained by computer simulation were extended to perform a life cycle cost analysis. There, the additional initial cost incurred for insulation was compared with the cumulative net present values of long-term economic benefit achieved in the form of the operational energy saving.

$$P = A\left\{\frac{(1+i)^n - 1}{i(1+i)^n}\right\} \tag{1}$$

where,

P = Present Value of Money
i = Discounting Factor/ Interest Rate
n = Project Life
A = Annual Worth

Eq. (1) was used to calculate the present value of progressive energy savings over the lifespan of the building [45].

The building life itself is an arguable topic among the research community. Some of the studies have taken it to be as small as 10–20 years [6,8–10,13–17,21], while some others recommend it to be 50 years [46]. 10% was taken to be the discounting factor, which was proven to be a typical value in Sri Lankan context [7]. Hence, three cases: 10 years, 20 years and 50 years, were considered based on 10% discounting factor in the analysis.

There are other factors that would have been ideally considered the life cycle cost analysis. The required load of the air conditioning equipment would inevitably become lesser after insulation and it marks a considerable reduction of the initial cost. However, it was not considered in the analysis, since it significantly affects the sensitivity of the heat gain to the cost figures.

The degree of land recovery and the maintenance costs are the other factors which were neglected in the analysis. The insulation system was proven to provide an unrestricted access [42], these parameters were considered to be cancelled out over the flat-slab options considered.

Each material related cost calculation was done with respect to standard BSR values and the electricity cost incurred by air conditioners was calculated according to the rates of Ceylon Electricity Board, Sri Lanka. Since the considered aspect was an ordinary office building, operational period which directly affects the cooling energy demand was taken as 0800–1700 h. (Other essential details related to cost calculation were listed in Appendix A)

In addition, the Life Cycle Cost Analysis was used to compare the performance in comparison with a traditional clay tiled roof with a timber ceiling and a 3 mm foil insulation. In this case, the land recovery poses a significant difference in the cost figures to be considered. Since this study mainly focuses on the thermal performance of the systems, it was not considered in the analysis. (The other relevant details of the virtual model were as listed in Appendix A).

4. Results and discussion

4.1. Thermal performance comparison of the novel roof slab insulation system with prevailing techniques

As described in Section 3.1, the thermal performance comparison between the novel roof slab insulation system and existing techniques was done using the temperature readings obtained from prototype model testings. Here, both top and bottom surface

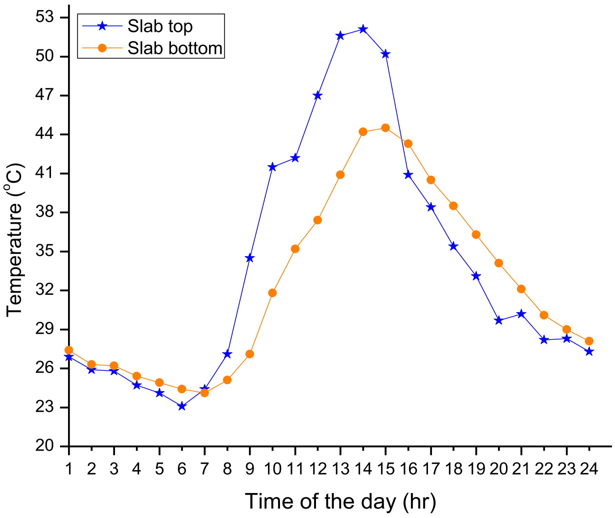

Fig. 9. Slab top and slab soffit temperatures of the control experiment over a period of 24 h.

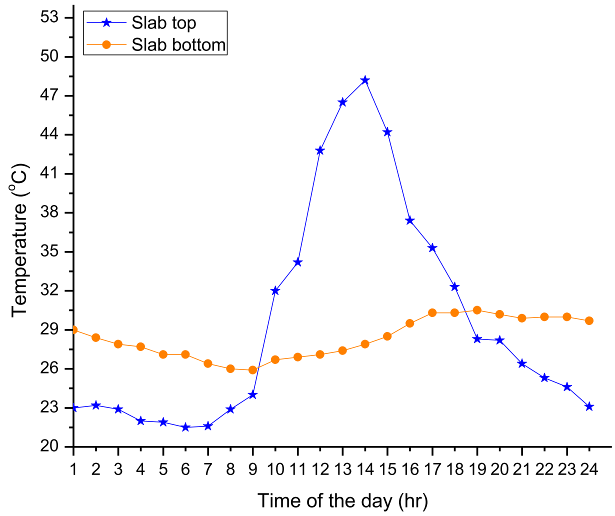

Fig. 11. Slab top and slab soffit temperatures of the intermittent-stripped system (newly designed system) over a period of 24 h.

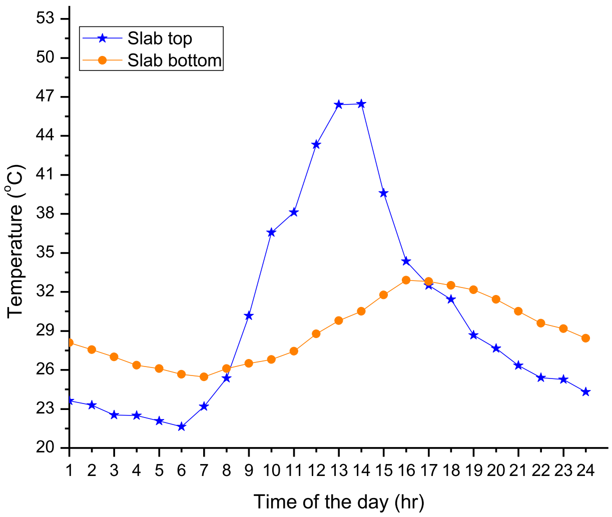

Fig. 10. Slab top and slab soffit temperatures of the system with continuous-strip supports over a period of 24 h.

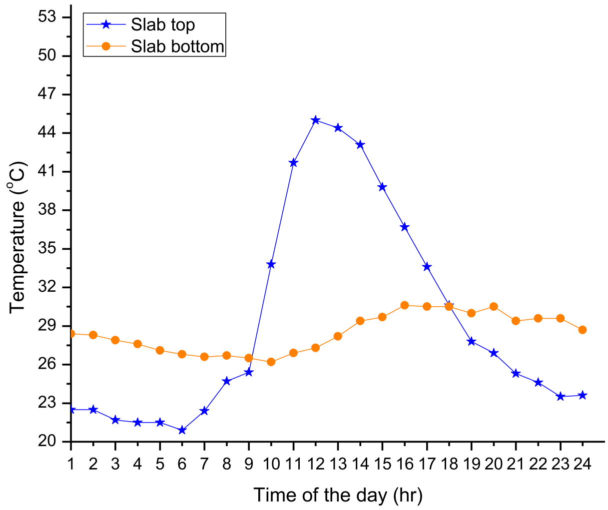

Fig. 12. Slab top and slab soffit temperatures of the system without any supports over a period of 24 h.

temperatures of each roof slab system were obtained using the data logger. Slab top and slab soffit temperature readings of each system mentioned in Section 3.1 are as shown in Figs. 9 –12 respectively.

Fig. 9 shows the slab top and slab soffit temperatures of the control experiment over a period of 24 h. It shows insulation characteristics to a certain extent due to the thermal mass effect of the roof slab. However, the soffit temperature has reached 46 °C, which is a significantly higher value in comparison with the other three cases tested. The results produced by the model with supports of continuous strips are indicated in Fig. 10. Predictably, it reveals a significant reduction in soffit temperature in comparison with the uninsulated (control) system. Figs. 11 and 12 elaborate the temperature variations of the discontinuously supported system (the novel system) and the system with continuous insulation respectively. They indicate that the behaviours of those two systems are nearly the same. It indicates that the new system is optimized in way of not accumulating a significant effect on thermal performance from the discontinuous concrete strips.

These results further emphasise that the concrete supporting strips of the discontinuously supported system do not have any notable impact on its thermal performance.

The absolute heat gain reduction by this system has to be found by a separate study by comparing the ambient temperatures and the temperature inside the room. It could not be found out with these set of temperatures as the thermal mass is small in this case. However, it has been proven through a previous study that the system by Halwatura and Jayasinghe has a heat gain reduction of 75% [41]. According to the above figures, it is evident that the new system performs better than the Halwatura and Jayasinghe system in thermal aspects. Hence, it can be deduced that the novel roof slab insulation system has a heat gain reduction of more than 75%.

4.2. Thermal performance comparison with an insulated Calicut tiled roof

As described in Section 3.2 the thermal performance with ordinary Calicut tilled roof was performed using an actual scale model testing. Temperature readings were obtained with the aid of the Data Logger correspondent to the experimental methodology described in Section 3.1.

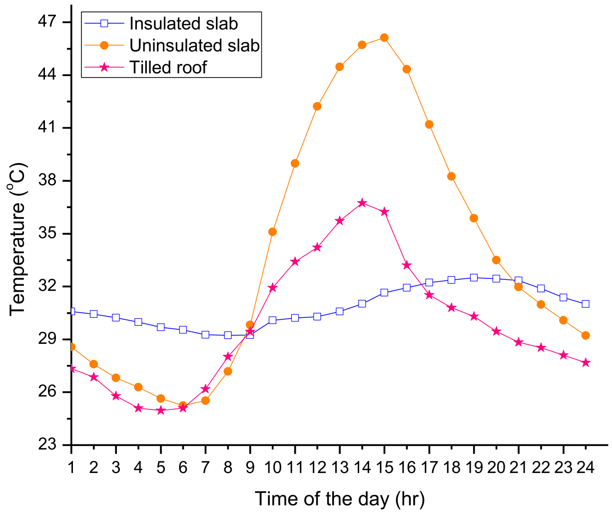

Fig. 13. Bottom surface temperatures of the insulated slab, uninsulated slab and Calicut tiled roof over a period of 24 h.

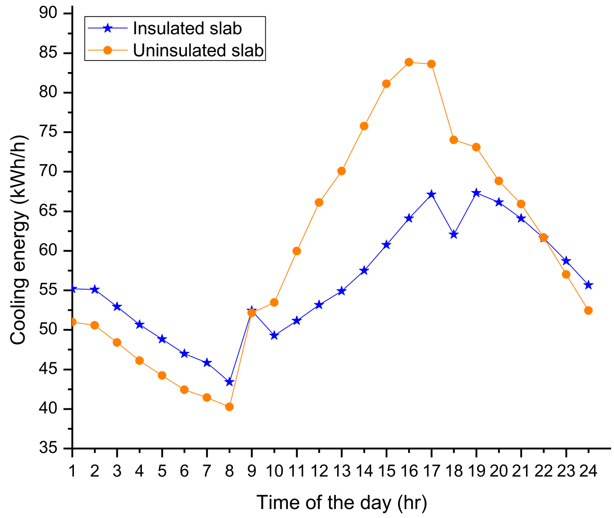

Fig. 14. Cooling energy required for insulated and uninsulated slabs over a period of 24 h.

Table 1
Slab top and soffit temperature readings, time lags and decrement factors of each roof systems.

Type of the roof	Slab top maximum temperature (°C)	Slab soffit maximum temperature (°C)	Time lag (hours)	Decrement factor
Uninsulated roof slab	54.0	46.1	2.0	0.85
Roof slab insulation system	56.0	32.5	5.0	0.58
Ordinary Calicut tilled roof	58.8	36.7	1.0	0.62

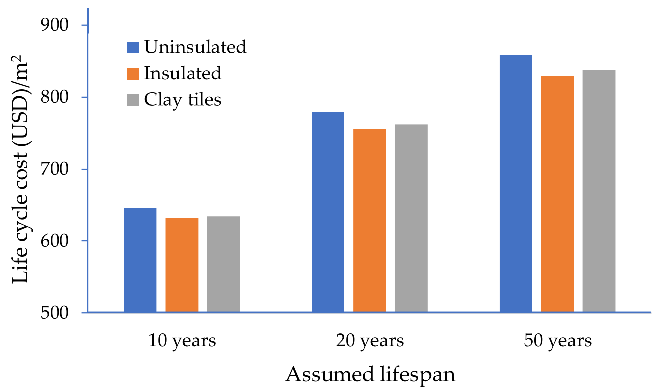

Fig. 15. Life cycle cost assessment for different lifespans assumed.

Fig. 13 shows the results obtained by the actual scale model testing. Here, a comparison between an uninsulated roof slab, an insulated roof slab which is the newly designed slab insulation system and a clay-tiled roof was obtained. According to the obtained results, the top surface temperatures were almost the same, with a slight edge to Calicut tiled roof. It was due to the lower Albedo value of Calicut tiles due to its relatively darker colour.

But there were considerable differences among the slab soffit temperature readings of considered scenarios as shown in Fig. 13. Corresponding slab top and soffit temperature readings, time lags and decrement factors of each case are as listed in Table 1.

Examining the soffit temperature readings, it can be clearly concluded that the insulated slab performs even better than a Calicut-tiled roof, which is proven to be the most popular roofing material due to the thermal comfort it provides [6]. That scenario is further verified by the least decrement factor of 0.58 correspondent to the new roof slab insulation system.

4.3. Peak cooling load reduction of the slab insulation system

As described in Section 3.3, the office building of 15 m × 15 m was used to access the peak cooling load reduction through the novel roof slab insulation system. The virtual model was simulated using "Design Builder v4" software package to find out the cooling load required to achieve neutral operating conditions on a typical sunny day. The neutrality temperature was taken to be 26 °C which was proven to be a reasonable value for tropical climatic conditions [44]. In Section 4.2 it is clearly shown that the concrete strips of discontinuously supported system do not impose and significant effect on the thermal performance of the slab system. Hence, the insulation layer was added using design Builder software neglecting the concrete strips.

The cooling energy requirements obtained for this particular building under the conditions mentioned are shown in Fig. 14. (Further details of the virtual model were listed in Appendix A). The displayed results are for discontinuously supported insulation system (novel slab insulation system) and 125 mm thick uninsulated RCC roof slab. Even though the simulations were carried out for all the four options specified in the methodology, only the graph obtained for the discontinuously supported system was presented here since the energy requirements for each insulated systems differ by less than 1% of each other.

It is clearly evident in Fig. 14 that the peak energy requirement on a typical sunny day can be reduced by about 20% by thermal insulating. (The corresponding calculation was available in Appendix A). This clearly reduces the intensity of the working rate of air conditioning equipment required, thus the initial investment itself too.

4.4. Financial feasibility of the slab insulation system

The calculated life cycle costs under the parameters mentioned in Section 3.4, for the 125 mm thick uninsulated RCC slab, the roof slab insulation system and the clay-tiled roof with a timber ceiling and 3 mm foil insulation are depicted in Fig. 15. Here also, only the analysis performed for the discontinuous-stripped system is presented here since the three insulated systems do not differ significantly from each other.

According to the results, it is apparent that both the other options possess a less life cycle cost than the uninsulated slab for all the options of lifespans considered. Quantitatively, it is apparent that about 5% life cycle cost saving can be achieved by insulating the slab. This, in fact, is the lower bound of the saving since the reduction in initial cost by insulation was not considered in the analysis.

The insulated slab performed even better than the clay-tiled roof, even without taking the land recovery into account. Hence, it is obvious that the system is economically feasible for a lifespan of more than 10 years, which is the practically the lower bound to be considered for a building.

5. Conclusions

It had been proven in the literature that a system developed by laying an insulation layer on top of a roof slab and covered by a thin protective screed provides a significant heat gain reduction through the roof. Further, a discontinuous supporting arrangement had provided a performance boost in terms of structural and durability aspects. This study focused on the thermal aspects of this insulation system.

Small-scale physical model testing proved that the effect of the supporting concrete strips to its thermal performance is negligible. Further, a comparison with literature derived that this system achieves a heat gain reduction of more than 75%.

Then, the experimental setup was extended to an actual scale model to assess the performance under real conditions. There, the system performed well and resulted in a better thermal performance than even a Calicut-tiled roof with a timber ceiling with a 3 mm-foil insulation.

A computer simulation was used to find out the energy-saving potential by this insulation technique. A 20% of peak cooling load reduction was observed on a typical sunny day in tropical climatic conditions.

Finally, a life cycle cost analysis resulted that it is possible to achieve about 5% reduction in life cycle cost through insulation in comparison with an uninsulated roof slab, even without taking the reduction of cooling equipment load requirement into account. Further, the insulated system performs better than an insulated Calicut tiled roof with a timber ceiling, even without taking the land recovery into consideration. Hence, this system was proven to be economically feasible for any practical lifespan of a building. Based on the results of the study, the ultimatum is the proposed slab insulation system can be effectively used in tropical climates as a passive cooling remedy to the existing adverse temperature effects.

And also, the contemporary roof slab insulation system "heat insulation system for flat roof slabs" obtained a patent under Sri Lankan intellectual property act No. 36 of 2003 and under the international patent classification (IPC: E0C 1/100, B28B, B28C) with the patent number: 17803.

Declaration of Competing Interest

All the authors thereby state that there is no conflict of interest.

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Appendix A

A.1. Details of the virtual model used for computer simulation performed using Design Builder v4

Basic details of the model	
Plan area of the building	15 m × 15 m
Number of stories	Three
Basic location	Moratuwa, Sri Lanka
Latitude	6.79° N
Longitude	79.9° E
Altitude	30 m
Wind exposure	Normal
Nearest weather station	Ratmalana, Sri Lanka
Activity details of the model	
Type of the building	Office 24/7
Occupation rate	0.1/m^2
Metabolic rate	Corresponds to light office work
Energy generation by equipment	10 W/m^2
Construction details	
The thickness of the walls	225 mm
Walling material	Engineering bricks
Structural slab thickness (insulation system)	100 mm
Protective screed thickness (insulation system)	40 mm
Structural slab thickness (uninsulated slab)	125 mm
Percentage of openings in E-W direction	0%
Percentage of openings in N-S direction	30%
Thermal properties of construction materials	
"U" value of concrete blocks	0.51 W/mK
"U" value of concrete	1.70 W/mK
HVAC details of the model	
Neutrality temperature	26 °C
Coefficient of performance (COP)	2.0
Supply humidity ratio	0.008

A.2. Peak cooling load reduction calculation

Peak cooling load from roof slab insulation system = 67.32 W

Peak cooling load from uninsulated RCC slab = 83.82 W

Peak cooling load reduction of the roof slab insulation system $= \{1 - (\frac{67.3199}{83.8256})\} \times 100\% \ = 19.69\% \approx 20\%$

A.3. Essential details related to cost calculation

It was considered that 1 USD = 160 LKR (Sri Lankan Rupees)

The rates were reasonable market rates by 2018

Initial cost

In general, the construction cost of Rs. 45,000/ per m^2 was considered in the analysis per the expert judgements related to the field of building construction.

The cost of 40 mm protective screed and discontinuous strips of the insulated slab was separately calculated considering the cost of Rs. 4050/ per m^2

The uncommon cost values (although there was a sloping roof in one model, it was not common for the other two models) for considered three scenarios were calculated according to the standard BSR values.

Cost of insulation

The rate of polystyrene was taken to be Rs. 900/ per m^2

The rate of 3 mm thick foil insulation (used in clay tiled roof) was taken to be Rs. 130/ per m^2.

Cost of electricity

Electricity cost was calculated according to the 2018 CEB rates (Ceylon Electricity Board). They are as listed in Table A1.

Table A1
Electricity charges in Sri Lanka (source; www.ceb.lk/commercial-tarif).

Monthly electricity consumption (kWh)	Unit Charge (Rs/Kwh)	Fixed service charge (Rs)
61–90	10.00	90.00
91–120	27.25	450.00
121–180	32.00	450.00
> 180	45.00	540.00

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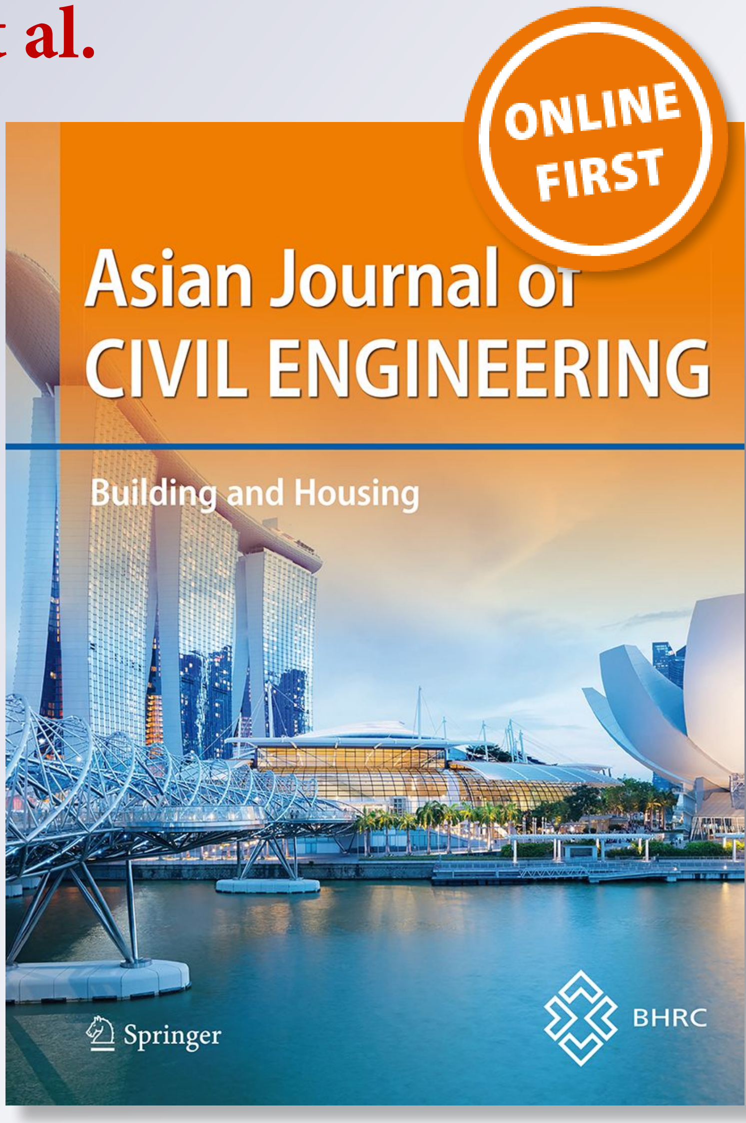

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ORIGINAL PAPER

An engineering approach towards the traditional beliefs in house construction

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Abstract

Although modern society is at the apex of science and technology, the shadows of traditional customs and beliefs in various fields can be seen. When the field of house construction is considered, traditional beliefs had been playing a considerable role which can be seen in Asian countries rather than European countries. Since hardly any engineering-based studies have been done to explore the significance of traditional beliefs in house construction, this paper tends to fill that gap and widen the thinking pattern of the society. The study reveals that 68% of stakeholders of house construction keep faith in traditional beliefs, while 32% do not. Among them, 81% accept not having three or more aligned openings in dwellings, 80.5% believe that it is not favourable to place ridge plate, beam or any load on top of the openings, 75.2% say that more west-facing windows are not suitable for houses while 65.7% say that west-facing verandas and balconies are not suitable for houses and 73.3% believe that using cross-walls for brick walls must be neglected. With respect to the engineering experiments done, not using cross-walls in brick wall construction was proven to be false with respect to the structural testing. Not having ridge plate, beam or any load on top of the openings was proven to be negligible in the presence of reinforced concrete (RC) lintel. But not having three or more aligned openings and not using west-facing verandas, balconies and more windows were accepted based on computational fluid dynamic (CFD) analysis and general explanations based on thermal comfort and structural behaviour of door and window frames. Hence, hasty neglection of traditional beliefs in house constructions by labelling them as superstitions should be changed. The acceptance or rejection of aforesaid beliefs has to be done with respect to the rational content of them, but not being blind slaves of them wasting both money and time.

Keywords Traditional beliefs in house construction · Superstitions in house construction · Feng shui · Vastu shastra · Cross-walls · West-facing houses · Aligned openings

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Introduction

Not only human beings but also all living beings from the tiniest insect which can hardly be seen with the naked eye to gargantuan creatures use safer places to live for mainly being protected from adverse climate changes and enemy attacks (Chandra et al. 2017). With the passage of time, the power of thinking of human beings gradually improved and made them superior to other beings and the master of them (Nehru 1930; Morris 1996, 1999). At the initial stage of human civilization, people used sheltered places like caves, dens and huts made on top of the trees as their dwellings. Eventually, people were nourished by the knowledge and attitude gained from nature. Then, they shifted their primary living places to well-prepared dwellings which were much more suitable for day-to-day lifestyle. These developed dwellings were called houses which are a place always suitable for human beings to live comfortably and a place that ensures an excellent balance between people and nature which brings about peace, happiness, health, wealth and prosperity to the inmates of the house (Patra 2006).

The house is the place where any family spends the most important, precious and valuable time of their lives. But it may not be the place where people spend the majority of hours of the day. For instance, doctors spend more than half a day at the hospitals, engineers spend weeks, months and years at their working sites and the professors spend most of their time at the universities. But none of those places are houses to any of them. Since the house is the place where people spend the most precious times of their lives with beloved family members, houses are considered sacred places like a shrine (Kithsiri 1995; Bhanumathie 1995). Hence, people have been making a huge effort to build their dream house that matches with each and every desire of them and their family members.

To achieve the goal of a properly built dwelling, people have been using various types of knowledge sources such as civil engineering and architectural knowledge as well as traditional knowledge in house construction (Chandra et al. 2017). Development of science and technology have influenced people to use civil engineering and architectural concepts for construction activities which refer to the science of construction, built environment, designation of space, creation and construction of the space required for making the day-to-day lives of people easy (Koranteng et al. 2015; Ulusoy and Kuyrukcu 2012).

Although construction materials such as concrete, cement blocks and bricks have been used from ages ago, modern technology seeks ways of improving the materials to make them more comfortable. In this phase, techniques such as building thermal insulation (Nandapala and Halwatura 2016; Chandra et al. 2019; Nandapala et al. 2018a; b; Silva and Chandra 2019), development of mew masonry concepts and sustainable building materials (Dehgan et al. 2018; Arooz et al. 2008, 2017, 2018; Jayathunge et al. 2019) and building information modelling (BIM) (Arunkumar et al. 2018) play a major role. Although the science and technology is in an extremely higher standard in the contemporary period, the shadows of traditional customs and beliefs can be seen in the fields such as building construction, town and country planning, as well as medicine. Thus, people have not totally abandoned their customs and beliefs in house construction, which are based on different fields like ancient architecture, astronomy, vastu shastra and feng shui (Chandra et al. 2011a, b, 2018). These beliefs in house construction have affected the lives of the people, have spread throughout society and have been lasting for years and years. And they continue to remain albeit with slight changes proving that they are inveterate in the society (Frenando 1998).

Almost all the customs and beliefs in building construction were nourished by vastu shastra, feng shui and various religious considerations of the society (Ranawaka Leelananda 2015). Vastu shastra which belongs to the period 1500–1000 BC is an ancient Indian knowledge as well as a science of architecture, planning and designing (Patra 2006). The word vastu originally was derived from the keyword "vas" that meant dwell or dwelling place (Arya 2000; Patra 2009). Hence, the term vastu conveys a place of human dwelling of more than a single household life. Feng shui is an ancient Chinese wisdom which literally means "wind and water" and it has influenced the layout and the design of cities and buildings (Koranteng et al. 2015; Huang 2012). The origination of feng shui was in China, then it spread to the western countries and can be seen all around the world now (Mak and Nag 2005).

The customs and beliefs which have been utilized in the field of house construction differ with respect to the climatic, religious and cultural parameters (Acharya 1946). Some of them have been labelled as superstitions and rejected by the society. But a considerable amount of them were transferred from generation to generation with slight differences and are still in practice. The superstitious influence in these beliefs can be a part of cosmology and myths such as para-religious and religious practices and beliefs embraced by people (Chandra et al. 2017). People are scared of these beliefs thinking that not obeying them would bring terrible results ending in death (Glazer 1978; Ofori et al. 2016; Rudski 2003). The most important thing is not "what other people believe" but "what is the rational basis of the beliefs and how they can be used in the real world". Hence, it is better to understand the rationality of these beliefs and use them in practical situations for the fruitfulness of the world.

A number of architectural and sociological studies have been done and explanations have been given for the traditional beliefs in house construction (Sarkar 2010; Chakrabarti 1998). But any deep investigation in terms of engineering and scientific context regarding the customs and beliefs in house construction can hardly be found. Therefore, it is necessary to launch a deep study as well as an analysis regarding these customs and beliefs and their engineering significance. When a civil engineer has a sound knowledge of these customs and beliefs as well as modern engineering technology, he would be able to cater a huge service to the society.

Structure of the article

The arrangement of the article is as mentioned below:

Section "Main objectives" contains the main objectives and specific objectives of the study.

Section "Identifying the most commonly used traditional beliefs in house construction and the reasons for admitting them" presents identification of the most commonly used traditional beliefs in house construction and the reasons for admitting them.

Section "Engineering approach towards key traditional beliefs in house construction" presents the approach towards the interpretation of the most commonly used traditional beliefs in house construction with respect to standard engineering experiments.

Section "Conclusions" contains the main conclusions which were achieved based on the current study.

Section "Recommendations and future works" describes the recommendations based on the current study and possible future works which can be done as extensions of the contemporary study.

Main objectives

The ultimate objective of the study is to analyse the behaviour of traditional beliefs in house construction with the aid of modern engineering technology and to discuss how meaningful beliefs can be used in modern construction fruitfully. The specific objectives are as listed below.

Specific objectives

- To identify the most commonly used traditional beliefs in house construction and the reasons for admitting them.
- To provide rational interpretations to the key beliefs using engineering technology.

Identifying the most commonly used traditional beliefs in house construction and the reasons for admitting them

Methodology adapted

The information regarding the commonly used traditional beliefs in the field of house construction was gathered from literature data of vastu shastra- and feng shui-related books, journals, newspaper articles and interviews which was done with the main stakeholders of house construction and ordinary citizens.

A detailed questionnaire survey was provided to the main stakeholders of house construction: civil engineers, architects, astrologers (experts of vastu shastra and feng shui), carpenters and masons covering all cultural, religious and locational variations of Sri Lanka. The questionnaire was carried out covering 75 in each category.

Most popular traditional beliefs in house construction were identified by means of the questionnaire and the reasons for the acceptance or withdrawal of them were identified. Then, the traditional beliefs which were of significant importance and needed to be analysed using the engineering technology were sorted out.

Results

Seven main traditional beliefs regarding house construction were identified and they are as listed below (Chandra et al. 2017; Ranawaka Leelananda 2015: Dayarathna 2010; Amarasooriya 2016);

- Not using cross-walls for brick wall construction.
- Not having three or more aligned openings (doors and arches) in the same row.
- Not disturbing the exact centre place of the house and the land plot.
- Not having more windows to the western direction.
- Not having west-facing verandas or balconies.
- Not having ridge plate, beam, etc., on top of the openings (doors, arches and windows).
- Not erecting walls, foundation, etc., on top of the ceremonial foundation stone.

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The usage of aforesaid beliefs was assessed by means of the questionnaire which was conducted in 2018. The questionnaire survey revealed that 68% of people believe in traditional concepts in house construction and 32% do not. This can be seen in Fig. 1.

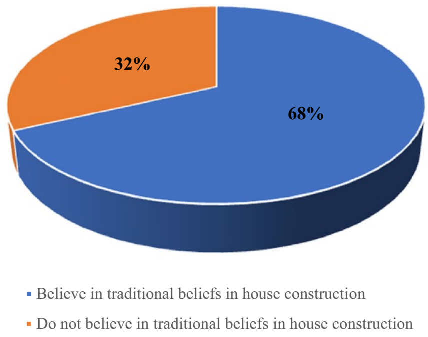

Fig. 1 Percentage of acceptance and withdrawal of traditional beliefs in house construction with respect to the whole sample

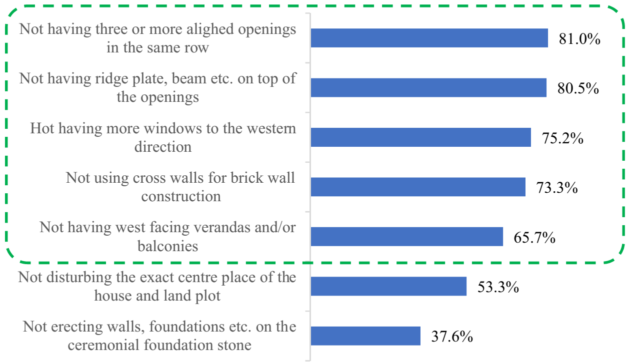

Fig. 3 The descending order of the beliefs in house construction with respect to the whole questionnaire results

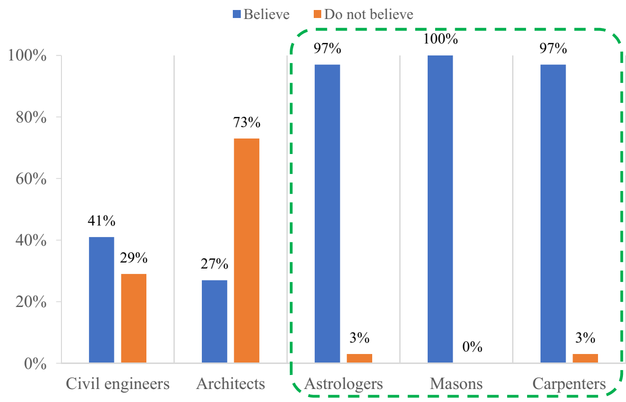

Fig. 2 Percentage of acceptance and withdrawal of traditional beliefs in house construction with respect to each category

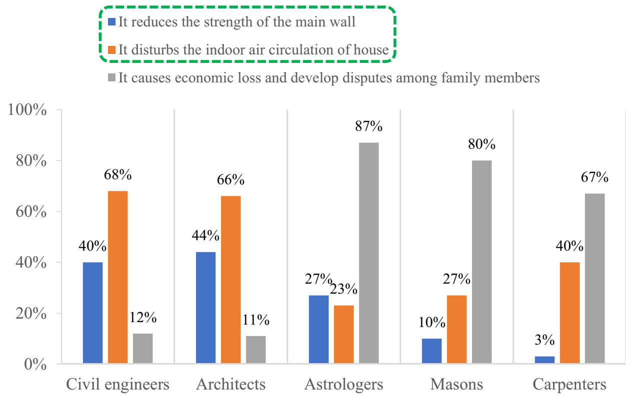

Fig. 4 Reasons for the acceptance of not having three or more aligned openings in the same row

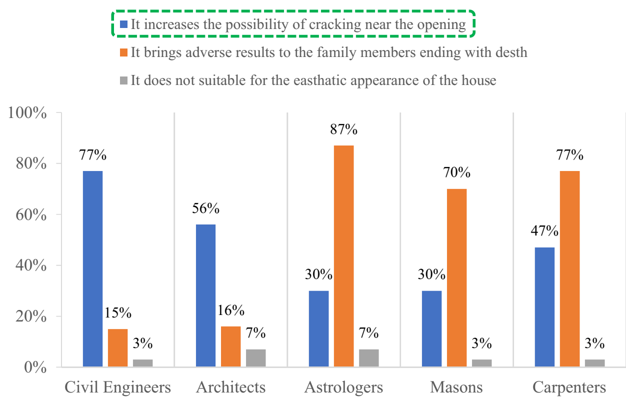

Fig. 5 Reasons for the acceptance of not having ridge plate, beam, etc., on top of the openings

Specifically, 61% of civil engineers, 27% of architects, 97% of astrologers, 100% of masons and 97% of carpenters have kept their faith in the traditional beliefs in house construction. The scenario is shown in Fig. 2.

In the questionnaire, some respondents have kept their faith in more than one belief and have mentioned more than one reason for admitting them. Each and every response was considered and the most commonly used beliefs among the society were sorted out; the ranking of them is as shown in Fig. 3.

The first five beliefs were the most popular in contemporary society. Out of them, not having more windows to the western direction and not having west-facing verandas and balconies were categorized together as, not having west-facing verandas, balconies and more west-facing windows.

Further, the reasons for embracing the selected beliefs were arranged with respect to the questionnaire results. Considering each response, the reasons for the acceptance of each belief were arranged as a percentage of each category.

The reasons for the acceptance of not having three or more aligned openings in the same row are as shown in the graph in Fig. 4.

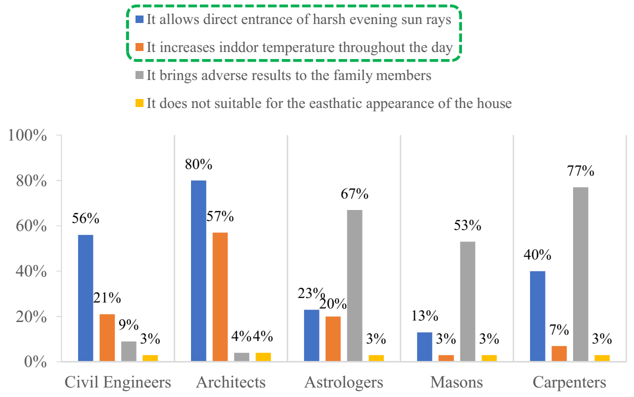

Fig. 6 Reasons for the acceptance of not having west-facing verandas, balconies and more west-facing windows

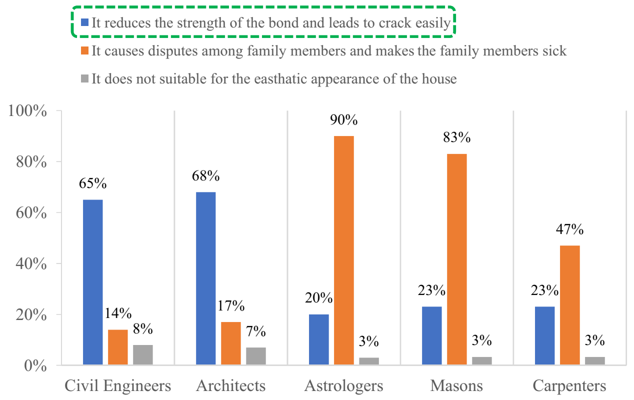

Fig. 7 Reasons for accepting not using cross-walls for brick wall constructions

The reasons for the acceptance of not having ridge plate, beam, etc., on top of the openings are as shown in the graph in Fig. 5.

The reasons for the acceptance of not having west-facing verandas, balconies and more west-facing windows are as shown in the graph in Fig. 6.

The reasons for the acceptance of not using cross-walls for brick wall constructions are as shown in the graph in Fig. 7.

Interpretations based on results

Among the sample of 375 stakeholders, civil engineers and architects were graduates in the fields of civil engineering and architecture and some had doctorates also. Some of the astrologers were graduates in arts subjects and the educational status of rest of them were in between ordinary level and advanced level, but the masons or carpenters would have hardly gone through at least secondary education. This reveals that civil engineers and architects are the people in the selected sample who have been nourished with theoretical as well as practical knowledge in the field of house construction. Hence, they have found the explanation to the considered traditional beliefs with respect to their technical knowledge. The highest percentage of highlighted responses, which have rational explanations in Figs. 4, 5, 6 and 7 was given by civil engineers and architects. Astrologers, masons and carpenters are responsible for the other unhighlighted responses which are based on the knowledge that were transferred from generation to generation mainly nourished by vastu shastra and feng shui.

Figure 2 clearly indicates that almost all the astrologers, masons and carpenters kept their faith in traditional beliefs in house construction. But being blind slaves of these beliefs will lead to the loss of both precious money and time. For an instance, the responses of majority of the astrologers, masons and carpenters indicate that not trusting the traditional beliefs will cause an economic loss in the family, will develop disputes among family members, will make family members regularly sick and will cause adverse effects ending in death. But, they are not providing any rational value and completely depend on the occult behaviour of vastu shastra and feng shui (Chandra et al. 2017; Ofori et al. 2016; Coote 1883; Ranjeet et al. 2016). The best option is choosing the traditional beliefs with significant importance and using them in real-world applications considering the rational explanations for accepting them.

Engineering approach towards key traditional beliefs in house construction

As shown in Fig. 2, not having three or more aligned openings in the same row, not having ridge plate, beam, etc., on top of the openings, not having west-facing balconies, verandas or more west-facing windows and not using cross-wells for brick wall construction are some of the most commonly used traditional beliefs in house construction. Hence, they were selected to be investigated with respect to engineering technology.

The approach towards "not having three or more aligned openings in the same row"

Methodology adapted

The models with aligned and non-aligned openings are as shown in Fig. 8.

The reasons for not having three or more aligned openings in the same row were gathered using field interviews and different literature sources such as journal articles, books and local newspaper articles (Chandra et al. 2017; Ranawaka Leelananda 2015; Sarkar 2010; Dayarathna

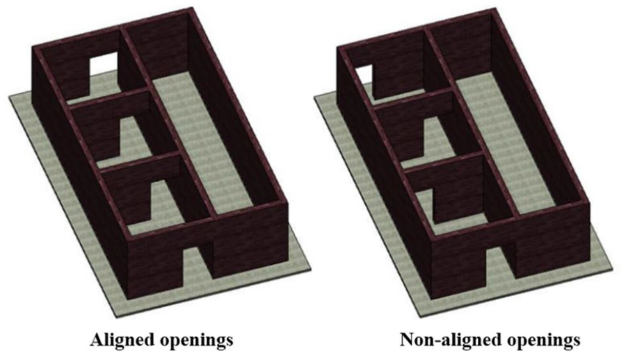

Fig. 8 A model with aligned openings and a model with non-aligned openings

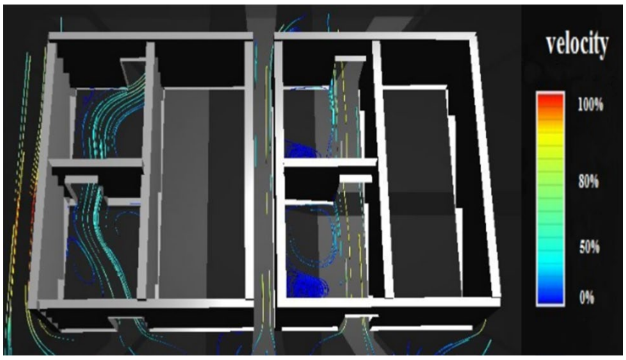

Fig. 10 Indoor air circulation with respect to 1 m/s wind velocity

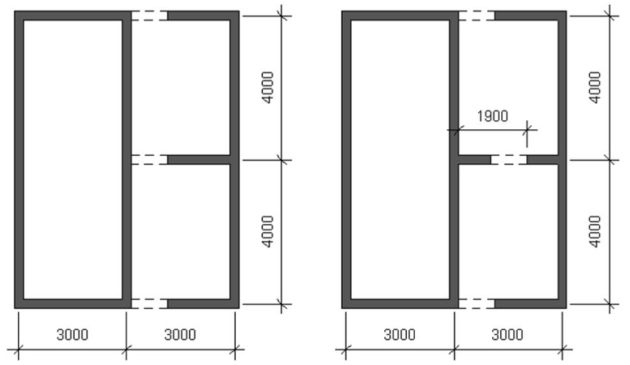

Fig. 9 Models with 4 m spacing between each opening

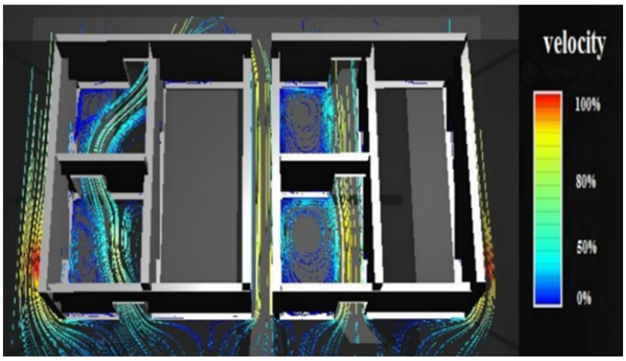

Fig. 11 Indoor air circulation with respect to 14 m/s wind velocity

2010; Amarasooriya 2016). The most common cases were accessed with respect to the questionnaire survey. The results are as shown in Fig. 4.

Among them, only two reasons, reduction of the main wall strength and disturbance to the indoor air circulation had certain scientific backing. The most opted reason, causing an indoor air circulation issue was further investigated using Autodesk flow design and computational fluid dynamics (CFD) software. The analysis was done with respect to various wind velocities that lie between 1 and 14 m/s which cover the minimum and maximum wind range of Sri Lanka (Wind Colombo, Wind speed Sri Lanka, Weather Online 2016; World Weather, Local Weather Forecast 2016). Based on the general arrangements of dwellings, room sizes are 10 m × 12 m, 12 m × 14 m, 13 m × 15 m and the opening sizes are about 1.2 m × 2 m. The computer simulation was done representing aforesaid scenarios and a plan view of the sample model is as shown in Fig. 9.

Results

The experiment was done for wind velocities from 1 to 14 m/s using the models having 3 m, 3.5 m, 4 m and 4.5 m

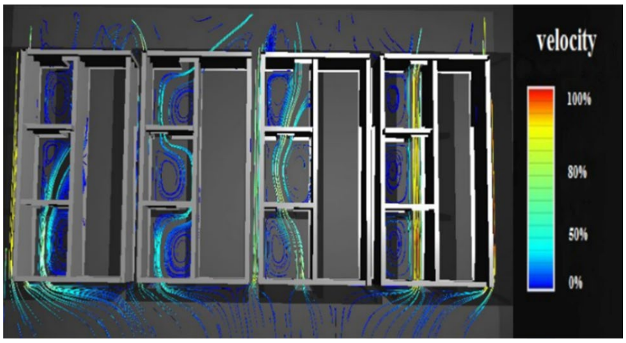

Fig. 12 Indoor air circulation of a model with four openings with respect to 4 m/s wind velocity

space between each opening. The indoor air circulation status of the models with three openings having 4 m spacing between two openings with respect to 1 m/s and 14 m/s wind velocities is as shown in Figs. 10 and 11.

Further, the indoor air circulation status of the models with four openings with 4 m spacing between two openings with respect to 4 m/s wind velocity was accessed. The scenario is as shown in Fig. 12.

Interpretation based on results

When the openings are aligned in a row, flow lines rushed through the openings and resulted in a lack of airflow in other spaces. Since flow lines with sufficient wind speed hardly circulate through other spaces of the house, those places become less ventilated.

When the openings are not aligned, flow lines get obstructed by walls and circulate with turbidity. It allows the circulation of flow lines with more than 50% of the original wind velocity to other spaces. Since the flow lines sufficiently circulate through other spaces of the house as well as through the openings, the whole house becomes properly ventilated.

When wind speeds approach higher values, some amount of flow lines circulate through other spaces even when the openings are aligned, but it is not a satisfactory situation which can be compared with air circulation when the openings are not aligned.

When there are more than three openings, the results are clearly verified. Flow lines with considerable velocities can be seen in every part of the model when the openings are not aligned. But when the openings are aligned, a rush stream of flow lines can be seen through aligned openings and flow lines which can be seen in other the spaces of the house contain nearly zero velocity.

The approach towards "Not having ridge plate, beam, etc., on top of the openings"

Methodology adapted

The view of the main door under the roof ridge and a door exactly under a beam is as shown in Fig. 13.

Similar to the previously described case in Sect. "The approach towards "Not having ridge plate, beam, etc., on top of the openings"", here also the main reasons for the adaption of the belief were lined up using a questionnaire survey. The outcomes are as shown in Fig. 5. The one and only response which had a rational explanation "increasing the possibility of cracking near the openings" was further investigated using the finite element modelling (FEM) software SAP2000.

For the FEM, a model with a plan area of 3.6 m × 5.0 m with an opening of 1.2 m × 2.2 m was selected considering the general room and opening sizes of a house. The model was prepared with 250-mm-thick membrane wall of brick masonry having a unit weight of 22 kN/m^3, elasticity modulus of 1×10^6 N/mm^2 and 0.3 Poisson's ratio. The FEM model was meshed into 0.2 m × 0.2 m meshing. The general 3D view and the model which was used in FEM are as shown in Fig. 14.

According to the structural calculations based on British standards (BS8110), the uniformly distributed roof load (UDL) acting on the ridge plate is about 3.5 kN/m. Hence, considering even the worst aspects loads from 3 to 7.5 kN/m within 0.5 kN/m intervals were used for the analysis. The loading was done for the three scenarios as shown in Fig. 15 such as, load is acting above the exact centre of the opening (1), the load is acting eccentric from the exact centre of the opening (2) and the load is acting away from the centre of the opening (c). Maximum compressive force (F22) which represents the maximum compressive stress at the critical regions of the openings was separately recorded with respect to the three loading scenarios and loading from 3 to 7.5 kN/m.

Results

Under the loading, critical stresses were observed near the regions marked in Fig. 16.

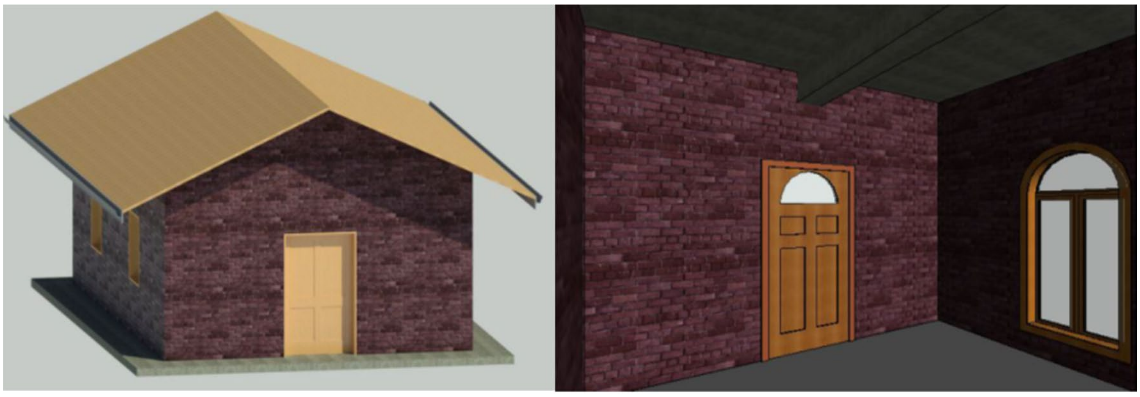

Fig. 13 Main door exactly under the roof ridge and a door under a beam

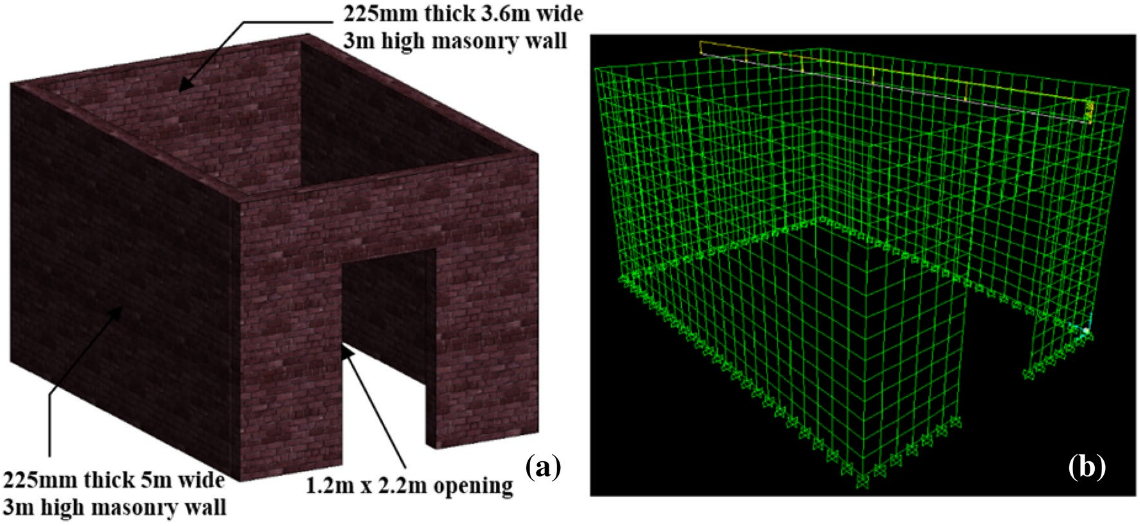

Fig. 14 3D view (**a**) and the analytical view (**b**) of the considered model

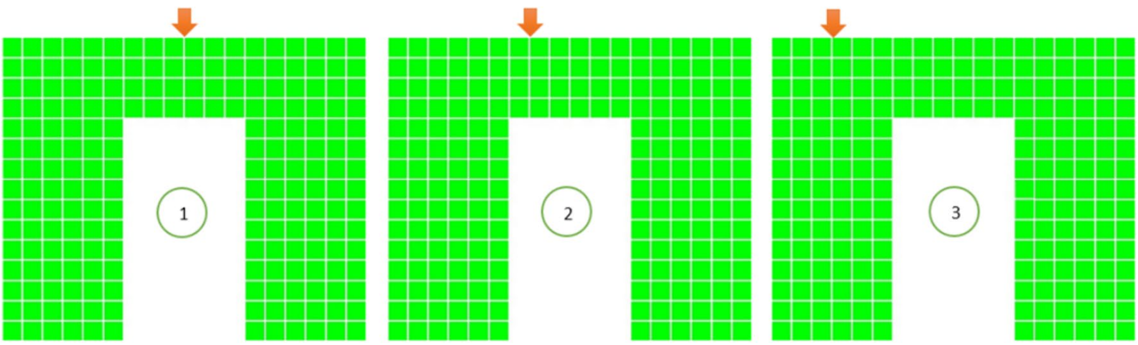

Fig. 15 Loads above the exact centre of the opening (**a**), loads act eccentric from the centre of the opening (**b**), load act away from the centre of the opening (**c**)

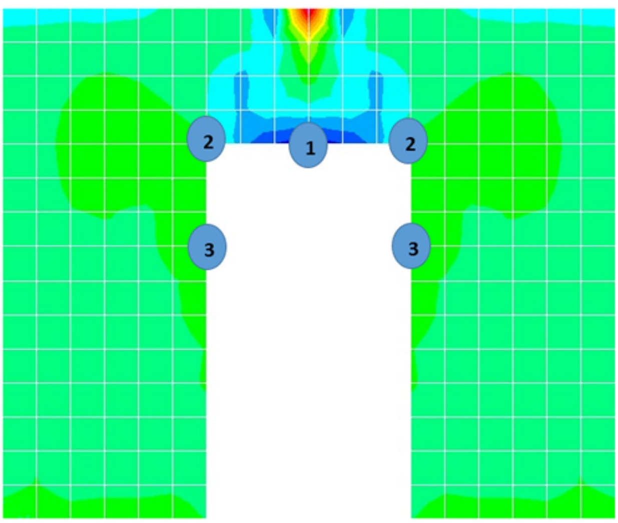

Fig. 16 Regions where the highest stress values were observed

Scatter diagrams which represent the maximum compressive force vs applied load when the loads acted at the exact centre point, eccentric from the centre and away from the centre are as shown in Fig. 17.

Since the maximum compressive force was observed due to the eccentric loads from the exact centre of the openings, the investigation was extended to figure out the exact loading point which provides the maximum stress. For that, 4kN/m load was applied from the exact centre place of the opening to the corner of one edge of the opening. The results are as shown in Fig. 18.

Interpretation based on results

The structural effect of having a beam or a ridge plate on top of the openings is the load transformation through the openings. The belief says not to place beam, ridge plate or any loading member exactly above the centre of the opening.

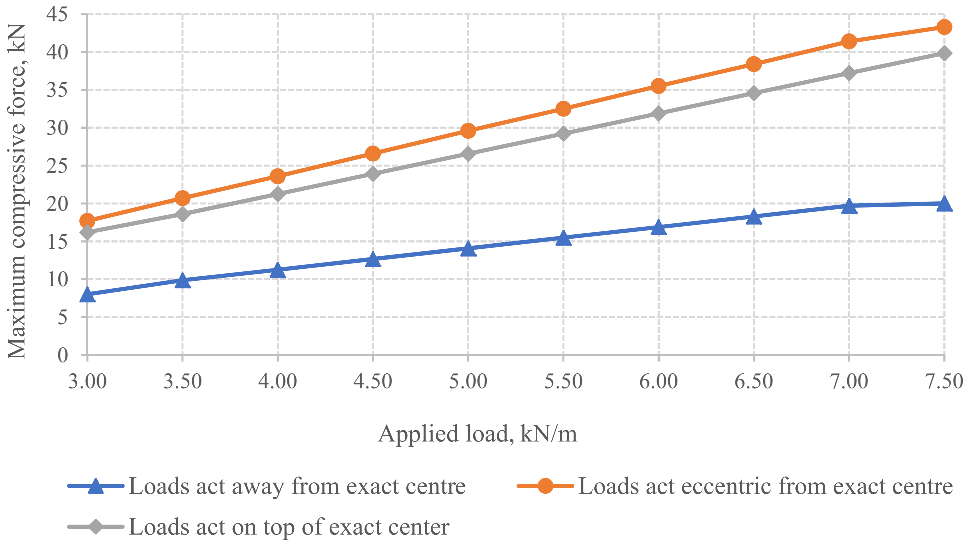

Fig. 17 Compressive force at critical regions of openings vs applied load

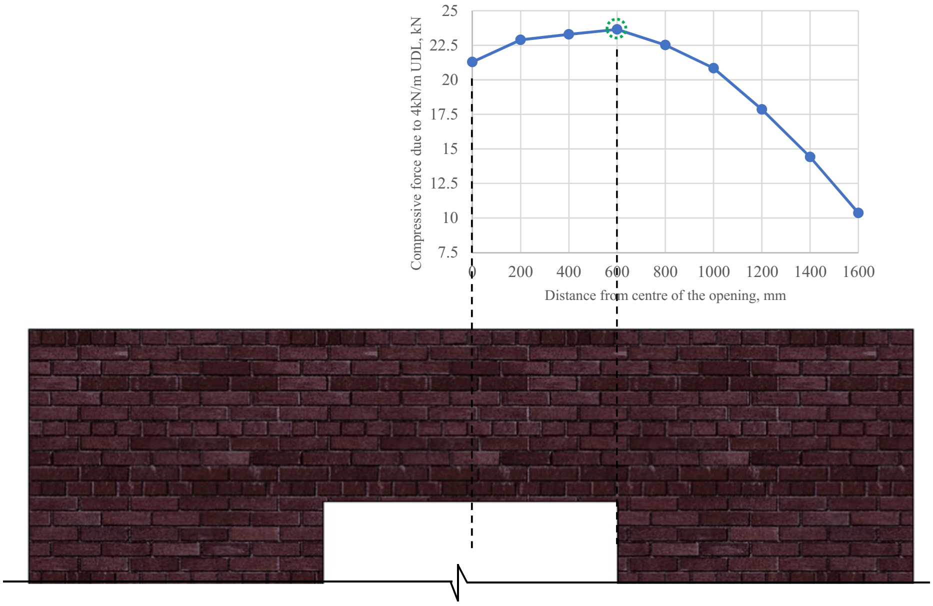

Fig. 18 The variance of compressive force vs distance from the centre of the opening due to 4 kN/m UDL

But as shown in Fig. 18, FEM results clearly show that the maximum stress develops near the openings when the load acts at the edge of the opening. Further, the intensity of the stresses decreases when the load gets away from one edge of the opening. But in the presence of reinforced lintel (RC lintel), no excessive stresses will be attributed to the openings.

The approach towards "Not having west-facing balconies, verandas or more west-facing windows"

For this aspect, no engineering experiment was adapted, since the scenario could be explained with general knowledge. In most of the houses, verandas and balconies are not placed facing to the western direction and hardly any west-facing window is used. The belief says, when the verandas, balconies or windows are placed facing west, it will adversely affect the family members by making them easy victims of illnesses, creating mortal accident situations, etc. It is very obvious that these explanations cannot be given any engineering rationale. But, the rule should have certain hidden meanings.

Usually, family members get together at evening and spend their leisure time in balconies and verandas. But when those verandas and balconies are west-facing, harsh evening sun rays will disturb the people who spend time in those places. And also, when the window frames are made of timber, they may be severely twisted due to the harsh evening sun rays. And also, evening sun rays enter the house through west-facing windows creating a warm building interior. It causes a thermally discomfort condition inside the house even during late evening hours making the inmates uncomfortable.

The approach towards "Not using cross-walls for brick wall construction"

Methodology adapted

The appearance of a brick wall with a cross-wall and a brick wall without a cross-wall is as shown in Fig. 19.

Among the responses of the questionnaire, the rational reason for not using cross-walls for brick wall constructions is the reduction of the strength of the bond leading it to be cracked easily. To check the structural behaviour of cross-wall junctions and non-cross-wall junctions, previously done test results (Weerasinghe et al. 2011) by one of the authors were used.

In this study, bricks which were manufactured satisfying the SLS 39:1978(2) were used, with mortar joint of 15 mm thickness and 1:6 cement–sand ratio that had been selected according to the BS 5628-1:1992; Table 1. Test panels of seven bricks long and ten bricks high as shown in Fig. 20 were selected according to the BS 5628-1:1992, Appendix A.2.2 which mentions "panels should be from 1.2 to 1.8 m in length with a minimum cross-sectional area of 0.125 m^2 and from 2.4 to 2.7 m in height. But, in special cases, it is required to test panels having dimensions outside these limits".

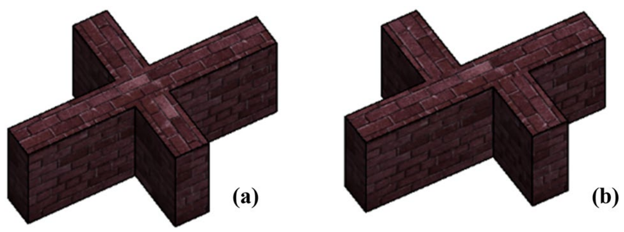

Fig. 19 A brick wall with a cross-wall (**a**) and a brick wall without a cross-wall (**b**)

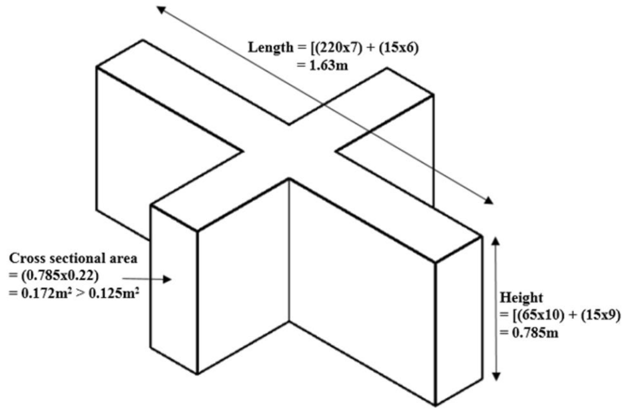

Fig. 20 Dimensions of the test panel

The prepared test panels are as shown in Figs. 21 and 22.

The physical testing was done in two sessions according to the BS 5628-1:1992, A.2.6. with a curing period of 28 days. The brief methodology of two test seasons is as mentioned in Table 1.

The loads were applied using the structural testing machine with the maximum capacity of 50 kN and the loads were equally distributed over the top surface of the main wall through three 25-mm-thick steel plates and one 50-mm timber plate as shown in Fig. 23.

Results

Test results of both tests regarding crack initiate load and failure load are as listed in Table 2.

Further, load reductions during every 1 min of rest time after application of a load of 10 units were observed using test no-02 and corresponding results are as shown in the scatter diagram in Fig. 24.

Interpretations based on results

In test 01 and test 02, crack initiate load differences between wall panel with a cross-wall and wall panel without a

Table 1 The brief methodology of two loading tests

Test no-01	Test no-02
1. Tests were carried out after 28 days of curing period	1. Tests were carried out after 28 days of curing period
2. Loading was continued until initial crack forming and continued until the failure stage of panels	2. Load of ten units was applied once and waited for 1 min without a load and again a load of ten units was applied and waited 1 min before the assignment of next ten loading units
3. Loads were applied only along the main wall for both types of test panels	3. Loads were applied only along the main wall for both types of test panels
4. Initial crack forming load and the failure loads were observed	4. Load reductions after every 1 min of rest time after application of loads of ten units was observed and crack forming load and the failure loads were also observed

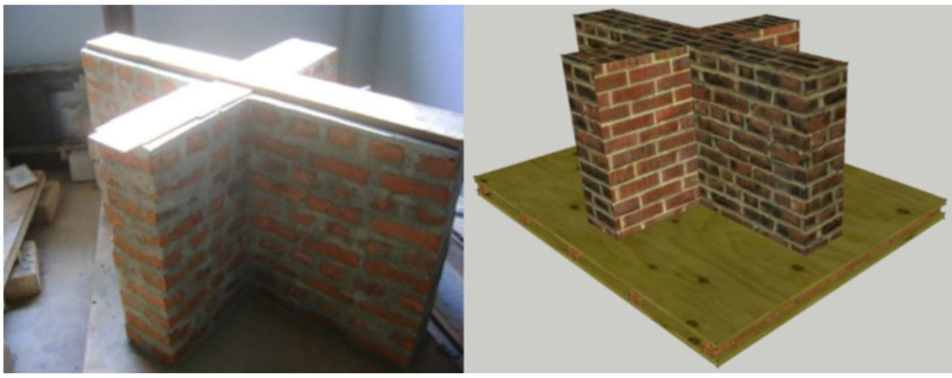

Fig. 21 A brick wall panel with a cross-wall junction (Weerasinghe et al. 2011)

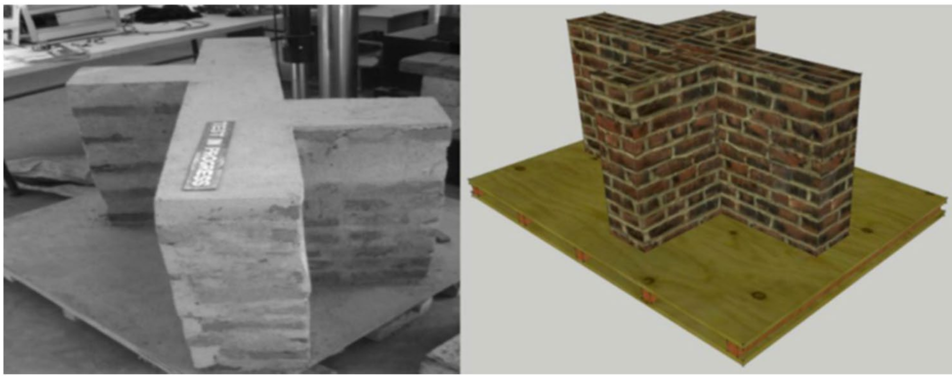

Fig. 22 A brick wall panel without any cross-wall junction (Weerasinghe et al. 2011)

Fig. 23 Applying the loads through the structural testing machine (Weerasinghe et al. 2011)

cross-wall were 4.42 kN and 1.35 kN, but the failure load differences were 0.43 kN and 0.57 kN. The wall panels without a cross-wall attributed higher strength situation. But since the crack initiate load contained a relatively higher value than the value of wall panels with a cross-wall, the ultimate strength of both types of wall panels can be considered to be approximately similar. The failure loads being very closer values further verify the rationale.

As illustrated in Fig. 24, both initial cracks and ultimate failure occurred in wall panels with a cross-wall, earlier than in the wall panels without a cross-wall. But there is no significant strength difference between the two types of wall panels. Hence, it can be considered that the strengths of wall panels with a cross-wall and without a cross-wall are approximately the same.

When the walls become non-load bearing, the structural effects due to the imposed loads can be neglected. But there is a construction difficulty in erecting cross-walls due to the complexity of the cross-wall junction. In the presence of a reinforced concrete column at the crossing point as shown in Fig. 25, each and every inconvenience can be easily eliminated.

Conclusion

Traditional beliefs in house construction are one of the main knowledge heritages mainly nourished with vastu shastra, feng shui, religious considerations and faiths which have been transferred from generation to generation. The aim of the study was not to discriminate such beliefs or label them as superstitions. Instead, the study tried to provide rational

Table 2 Test results regarding crack initiate load and failure load

Type of wall panel	Crack initiate load (kN)	Crack initiate load difference (kN)	Failure load (kN)	Failure load difference (kN)
Test no-01				
Without cross-wall	16.51	4.42	27.75	0.43
With a cross-wall	12.09		27.32	
Test no-02				
Without cross-wall	14.94	1.35	27.04	0.57
With a cross-wall	13.59		26.47	

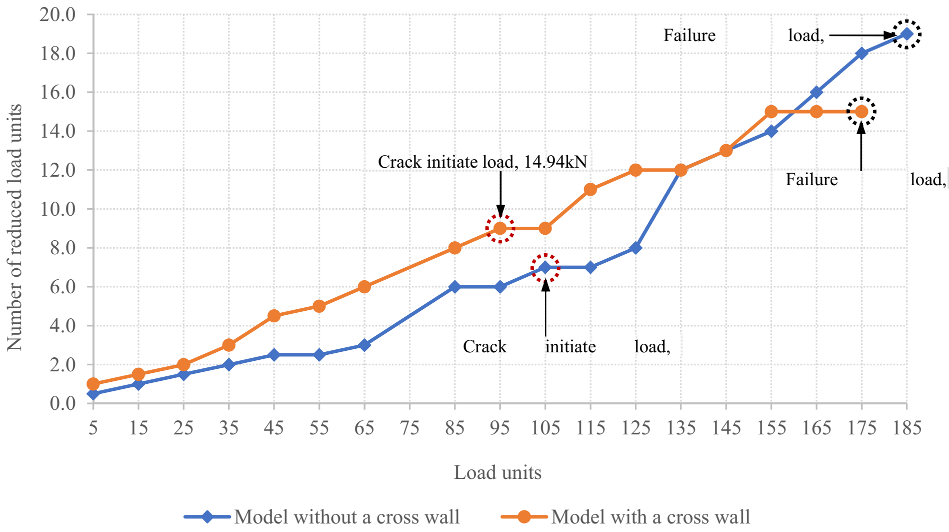

Fig. 24 The number of load units: reduced vs applied load units

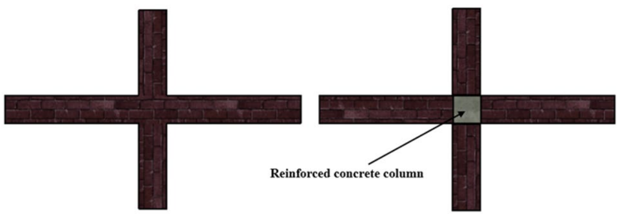

Fig. 25 A cross-wall junction without and with a reinforced concrete column

engineering explanations to selected traditional beliefs which can be studied with the aid of engineering technology.

The study reveals that the main reason for not having three or more aligned openings in a dwelling is the lack of sufficient natural ventilation in the house. And also, there can be issue for the privacy of inmates due to such opening arrangements. Hence, it is better not to have three or more aligned openings in dwellings as well as in any building.

Though the belief says not to place ridge plate, beam or any load on top of the exact centre point of openings, that aspect was proven to be wrong through the study, since the maximum stress development was observed when the load acted on top of one edge of the opening. In the presence of reinforced concrete (RC) lintel, every adverse effect gets eliminated. Since RC lintels are commonly used in present house constructions, this belief can be withdrawn.

West-facing verandas, balconies and windows create uncomfortable situations in terms of thermal comfort. It also leads to the twisting of window frames. Since there is significant importance in certain belief, it is better to admit these beliefs.

Through the final investigation, it was proven that there is no significant difference in structural strength between brick walls with and without cross-walls. When the walls become non-load bearing, every structural effect due to the imposed loads can be neglected. Hence, cross-walls can be used in brick wall construction in house constructions without having any dispute of structural strength.

The ultimate conclusion is that it is not better to withdraw the traditional beliefs in house construction by just labelling them as outdated pieces of information or be slaves of them wasting both money and time. The best idea is to accept or reject the traditional beliefs based on the rational explanations and utilize them in real-world applications when they are meaningful.

Recommendations and future works

The study was limited to a sample of 375 people for the questionnaire survey. But more elaborative responses can be achieved by expanding the sample size. And also the results can be further sharpened by extending the questionnaire to other countries also.

Physical model testing was only used for the cross-wall scenario. But the other three cases can also be physically tested using prototype models to obtain reliable outcomes.

If each and every traditional belief in house construction is withdrawn by labelling them as superstitions, the beliefs which contain rational explanations will never be extracted for use in real-world applications. These beliefs had been existing in the world long before the emergence of modern science. Even modern science has taken examples and guidance from them. In the past, traditional beliefs may have been introduced to ordinary people attributing them to occult repercussions of not obeying them, since the ordinary people did not have sound technical knowledge. Since they have been transferred from generation to generation, the occult behaviour may remain albeit with fewer changes and this could be the reason for questionnaire responses such as adverse effects ending in death, etc.

Hence, it is recommended to consider beliefs such as "not having three or more aligned openings" and "not having west-facing balconies and more west-facing doors and windows" which have rational explanations and engineering significance in real-world practices.

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Compliance with ethical standards

Conflict of interest All authors state that there is no conflict of interest.

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ORIGINAL RESEARCH

Developing a durable thermally insulated roof slab system using bamboo insulation panels

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Abstract

Traditional roofs can be effectively substituted by reinforced concrete roof slabs while gaining multiple advantages such as cyclonic resistance, possibility of future vertical extension and possibility of utilizing as an extra working space or a rooftop garden. Further, it adds a significant economic benefit from land regaining. However, the immediate space beneath the roof slab results in thermal discomfort and hence the inventions related to insulated roof slab systems have been increased recently. Although the expected thermal comfort could be achieved, most of the inventions use artificial thermal insulation materials such as polystyrene. This paper introduces a novel roof slab insulation system which uses the natural material of transversely cut bamboo layer as the thermal insulator. The proposed system minimizes the negative environmental impacts induced by the use of artificial insulation materials. The optimum insulation layer thickness is found to be 25 mm, which has acquired a 53% peak heat gain reduction with a decrement factor of 0.61 and a 3-h time lag.

Keywords Slab insulation · Natural thermal insulation · Bamboo insulation · Heat gain reduction · Global warming

Introduction

Countries like Sri Lanka, located close to the equator, experience tropical climatic conditions having a higher humidity level with low seasonal temperature variations. Most of the Asian countries with such climatic conditions are rapidly developing countries with challenges such as energy crisis and scarcity of usable land for construction [1]. As a result of the damages caused by this development, global warming increases at an alarming rate and has become one of the major issues in the planet [2]. Although scientists and researchers attempt to find measures against global warming, its effects do continue to affect. The world is on its path of facing far worse consequences of global warming such as ice melting and rapid rising of sea level, abnormal precipitation, hurricanes and storms, floods and droughts [3]. According to the recent studies, failure to take necessary actions against global warming would result in a 1.1–6.4 °C rise of earth surface temperature by the end of the twenty-first century [4]. Consequently, countries like Germany have determined to reduce the emission of CO_2 by 80% by 2050 [5].

Subsequently, people seek active cooling solutions such as Air Conditioning to overcome the thermal discomfort inside the buildings induced by global warming. Improved economic standards and availability have made the utilization of Air Conditioners popular among the people [1, 6]. But this should never be encouraged due to the higher energy demand and thereby the higher emission of Greenhouse gases [1, 7, 8]. The usage of Air Conditioning equipment in buildings has increased over the years; hence, a proper mechanism of minimizing the need of active cooling measures would reduce both household and national electricity demand [9–11]. Such systems can be replaced by passive

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techniques to improve the indoor thermal comfort while reducing the energy consumption [12, 13].

On the other hand, frequent natural disasters have occurred recently highlighting the significance of disaster resistant structures. Recent findings predict that the severity and the intensity of the natural disasters would be increased in the near future [14]. Disaster resistant structures serve the community saving their lives in the events of natural disasters by preventing sudden collapses. Saving the structures indirectly assists in mitigation of the emission of greenhouse gases by minimizing the repeated usage of embodied energy through preventing the rebuilding [1, 15]. Cyclones are a common scenario in tropical countries. Having conventional roofs made of clay tiles and roofing sheets makes the buildings vulnerable. The effect of the cyclones can be mitigated by increasing the robustness of the structures, which can be achieved by concrete roof slabs through its self-weight [1, 16, 17]. Further, it provides additional benefits such as the possibility of future vertical extension, the possibility of using as an extra working space and the possibility of having vegetation on the top. And also it adds a significant economic value by regaining the land [17–19]. However, the main drawback of roof slabs is the thermal discomfort in the immediate underneath space [1].

This issue can be effectively mitigated by insulating the roof slab. Although it requires an additional capital that can be paid back within a reasonable period of time by the reduction in operational cost [20–23]. Since about 70% of the total heat gain of a building occurs through roofs [24], a considerable amount of heat gain reduction could be achieved through the roof insulation. That has enhanced the enthusiasm of the researching community towards the investigation of effective roof insulation techniques [24]. Several of such tested across the world are listed in Table 1.

Halwatura and Jayasinghe have developed an insulated roof slab system suitable for tropical countries using a polystyrene layer as the thermal insulator [1, 16]. In that system, a 25-mm-thick polystyrene (thermal conductivity of 0.035 W/mK) layer has been used between a 40-mm protective screed layer and a 100-mm-thick structural slab [1]. It has been calculated that the air-to-air thermal resistance and the composite thermal conductivity of the system to be 0.9 m^2 K/W and 1.1 W/m^2 K, respectively [17].

Although the invention of Halwatura and Jayasinghe has been proven to be effective in terms of thermally and structurally, the system has been found to have issues related to durability since some water patches were observed on slab soffit in the long run [1]. Moreover, the concrete ratio of insulation layer was 16% [17]. Addressing this and the durability issue without harming the structural integrity, Halwatura and Jayasinghe system was further optimized by Nandapala and Halwatura [17].

In the system of Nandapala and Halwatura, the continuous strips of Halwatura and Jayasinghe system were converted into a discontinuous strip setup and thereby, the drain paths were added and the concrete ratio of the insulation layer was reduced to 3.3% [17] resulting a further decrement of composite thermal conductivity (corresponding calculation is as performed in "Appendix A"). Although the strip arrangement has been altered, it has not compromised the structural performance of the system [17].

Although the system of Nandapala and Halwatura is found to be sound in thermal and structural performance, the thermal insulation material used was polystyrene, (0.033 W/m K thermal conductivity) a product of crude oil extraction that contributes the most to the Greenhouse gas emission [29, 30]. Since it is unfavourable in terms of global warming, it was decided to prepare a suitable natural thermal insulation method to achieve the desired comfort levels. This paper describes a detailed study performed to invent a durable and thermally insulated roof slab system using bamboo insulation panels made of transversely cut bamboo. This system intends to achieve the domestic energy conservation which is highly conferential [31–33] as well

Table 1 Roof thermal insulation techniques tested across the world

Country	Insulation technique	Remarks
Florida, USA	Applying a cool paint	19% of energy saved on average, saved up to 38% on peak [25]
Italy	Applying a cool paint	Indoor temperature is reduced by 2.5 °C in comparison with outdoor [26]
Greece	6 cm of ventilated air gap	Daily heat gain is reduced by 56% [27]
Sri Lanka	25-mm-thick polystyrene insulation on a concrete roof	9 °C reduction in slab soffit temperature, about 75% reduction of heat flow [1]
A laboratory experiment	Combined application of aluminium reflector and polyurethane insulation	Heat flux reduction of 88% [28]
A laboratory experiment	10-cm plastic waste thermal insulation	About 70% effective insulation in comparison with ordinary insulation materials. However, considering the economic aspects, this is viable [29]

as the energy conservation of other commercial buildings by mitigating the need for air conditioners. And also, the novel insulation system "bamboo heat insulation panels for roof slabs" obtained a patent under Sri Lankan intellectual property act No. 36 of 2003 and under the international patent classification (IPC: E0C 1/100, B28B, B28C) with the patent number: 18880.

Objectives

Overall objectives

The main objectives of the study are to develop a roof slab insulation system using a natural thermal insulation material and assess the effectiveness of the slab insulation system in tropical climatic conditions.

Specific objectives

The specific objectives are as listed below:

- Investigation of natural thermal insulation solutions.
- Accessing the possibility of using an air gap as a thermal insulator.
- Studying the effect of air confinement through bamboo cut in the transverse direction.
- Studying the effect of thickness and number of bamboo layers and optimization.
- Calculating the peak heat gain reduction by the bamboo insulation system.

Materials and experimental methods

Investigation on potential natural thermal insulation materials that can be used in local conditions in Sri Lanka

The most important factor in any thermal insulation system is its insulation material. Hence, it is better to select a feasible thermal insulation material to achieve the desired comfort levels. Here, the necessary data of locally available natural materials that can be used as thermal insulators were gathered from the available literature.

Using an air gap as the thermal insulator

Small-scale physical model tests were conducted under typical summer days in the 1st week of September 2018 at the University of Moratuwa, Sri Lanka. Plan area of each model was 1.2 m × 1.2 m and height was 1.0 m. Thermal readings were recorded over five consecutive days using GL820 Midi Data Logger and a set of average hourly uninterrupted readings of 24 h were obtained considering the temperature readings with minimum deviations. The sample views of small-scale physical models are as shown in Fig. 1. Each physical model was constructed using half brick thick walls made of ordinary un-plastered bricks (0.51 W/m K) and reinforced concrete (1.7 W/m K) was used in roof slabs.

Fig. 1 Small-scale physical models used to assess the thermal performance

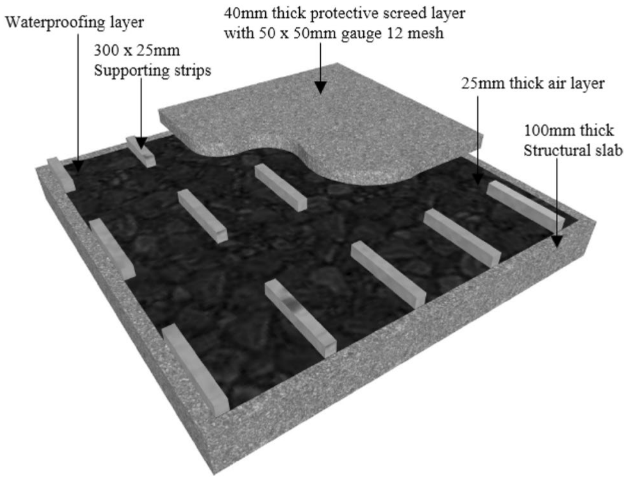

Fig. 2 Details of the slab insulation system with an air insulation layer

Models were prepared using the structural arrangement of Nandapala and Halwatura system [17]. Details of the slab insulation system with a 25-mm-thick air insulation layer are as shown in Fig. 2.

Using a bamboo cut in the transverse direction as a thermal insulation material

The experiment described in "Using an air gap as the thermal insulator" was corresponding to an insulation layer of unconfined air. Even in insulation materials such as expanded polystyrene, air confinement is used as a thermal insulator. Hence, it was decided to create an air confinement in such a way that the additional cost for the confinement is minimized and the system is conveniently constructible. Desired air confinement was achieved using bamboo cut in the transverse direction. Since bamboo is a rapidly growing plant which holds the Guinness record for the fastest growing plant in the world [34] the adverse effect imposed using bamboo for construction purposes is negated in a shorter span of time. In addition, it has been proven that bamboo is a good thermal insulator [35].

In a nutshell, the intention was to create an air confinement using a locally available, stiff natural material. And also, the impact to the environment due to the utilization of such material had to be minimized since the study focuses on sustainability. Satisfying all those requirements, bamboo cut in transverse direction does possess the qualities to be the ideal material. The planned structural arrangement with bamboo is shown in Fig. 3.

As shown in Fig. 3, the structural arrangement by Nandapala and Halwatura, which was experimentally verified to be capable of withstanding any practical load [17] was used here. Panel units are as shown in Fig. 4. They were pre-cast units and were placed as the thermal insulation layer in such a way that the air confinement is achieved. The bamboo layer was prepared using the same age and approximately the same size bamboo creating an approximate uniform distribution. One of the small-scale physical models which were constructed using the bamboo insulation system is as shown in Fig. 5. In this experiment, the thermal performance of the model with a 25-mm-thick bamboo insulation layer was compared with the one with a 25-mm polystyrene layer with respect to the temperature readings which were recorded during the same period of time.

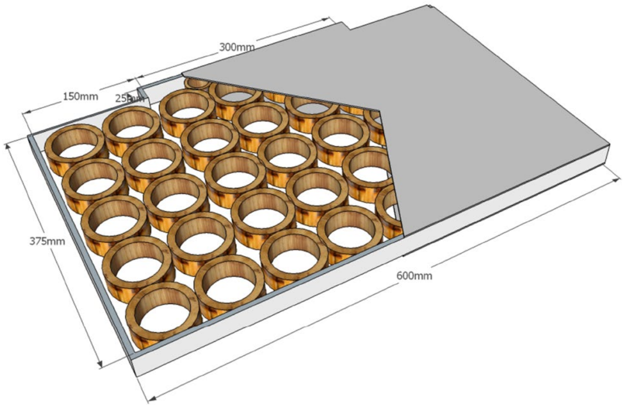

Fig. 4 Panel units used in the construction of bamboo insulation layer

Initially, the insulation layer was prepared using a set of 25-mm-thick bamboo panels. Since better thermal performance can be achieved by optimizing the insulation layer thickness and the number of layers, the optimization was done. The objective was achieved using a set of small-scale physical model testings containing the models with the dimensions mentioned in "Using an air gap as the thermal insulator". The thermal performance of the slab systems of 25 mm (1.0″), 50 mm (2.0″) and 75 mm (3.0″) bamboo insulation thickness was observed and the effect of the number of layers was investigated using two layers of 37.5 mm bamboo (1.5″). Here also, GL820 Midi Data Logger was used to measure the slab top and slab soffit temperatures of each model.

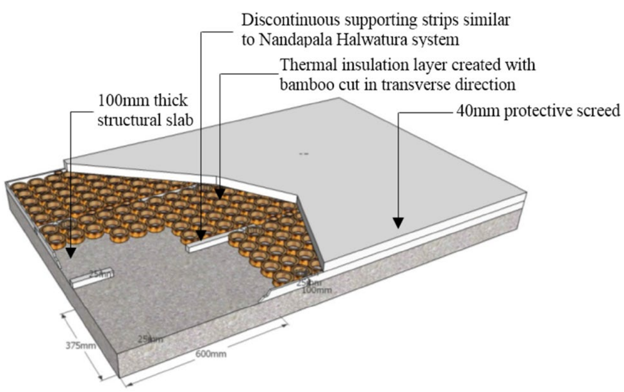

Fig. 3 Planned arrangement of the bamboo insulation layer

Fig. 5 Construction of the system with bamboo insulation

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Calculation of peak heat gain reduction by bamboo insulation slab system

The heat gain reduction due to the bamboo insulation system was calculated with respect to a 125-mm-thick uninsulated reinforced roof slab. Heat flow calculation was performed using the temperature difference between slab soffit and slab top temperatures and corresponding air-to-air resistivity values (the calculations and material properties are given in "Appendix A").

Since there was an air trapping in the bamboo insulation system, a computer simulation which was performed using "Design Builder V5" software package was used to obtain the air-to-air resistivity value. The virtual model was prepared similar to the actual model described in "Using an air gap as the thermal insulator" (details of the simulation model used in the experiment are as listed in "Appendix A"). Since the objective was to obtain the experimental air-to-air resistivity and corresponding "U" values (composite thermal conductivity), the virtual model was calibrated with respect to the inputs of measured outdoor temperature values. The slab top and slab soffit temperature readings of the actual model and computer simulation are as shown in Fig. 6.

Figure 6 shows that the simulation results are much similar to the results obtained through the physical model testing. Hence, air-to-air resistivity and corresponding "U" values of bamboo-insulated slab obtained through the computer simulation were used in heat flow calculations.

Results and discussion

Prevailing locally available natural thermal insulation materials

As mentioned in "Investigation on potential natural thermal insulation materials that can be used in local conditions in Sri Lanka", details regarding locally available thermal

Table 2 Properties of locally available natural thermal insulation materials

Natural thermal insulation material	Thermal conductivity (W/m K)
Banana and polypropylene (PP) fibre [36]	0.157–0.182
Bagasse [37, 38]	0.046–0.055
Corn cob [39, 40]	0.101
Cotton (stalks) [41]	0.058–0.081
Date palm [42, 43]	0.072–0.085
Durian [44]	0.064–0.185
Oil palm [45]	0.055–0.091
Pecan [46]	0.088–0.103
Pineapple leaves [47]	0.03–0.04
Rice [46]	0.046–0.056
Sunflower (cake from bio refinery) [37, 38, 45]	0.046–0.055
Sunflower (pitch) [48]	0.038–0.050
Straw bale [49, 50]	0.038–0.067

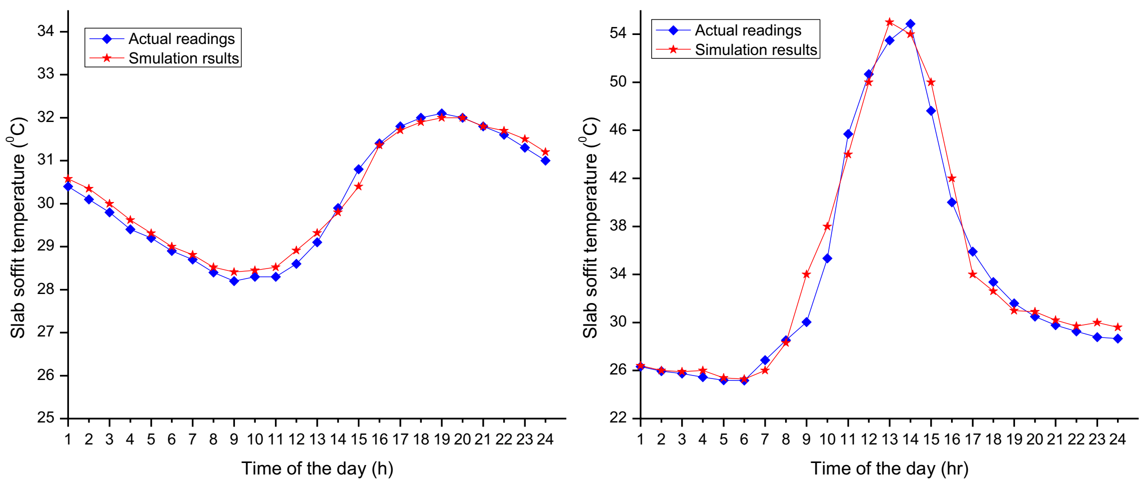

Fig. 6 Slab top and slab soffit temperature readings of the actual model and computer simulation

insulation materials were collected via a literature review. The summary of the literature data is listed in Table 2.

The thermal conductivity values of considered natural thermal insulation materials were in between 0.03 and 0.182 W/m K, and the thermal conductivity of polystyrene which was used in Nandapala and Halwatura system is in the lower bound of Table 2. Hence, it is clear that there is a possibility of substituting polystyrene by a natural thermal insulator and obtaining a reasonable degree of insulation.

An efficient thermal insulator needs to be a material with high porosity as it disturbs the heat conduction. The pores in the material absorb heat disturbing the conductive heat flow and reduce the composite conductivity of the system [4, 51]. According to this process, increasing the void ratio in the insulation layer should theoretically increase the effectiveness of the insulation system. Therefore, the extreme condition, a system with a 100% void ratio, a layer of air, was selected for a trial analysis.

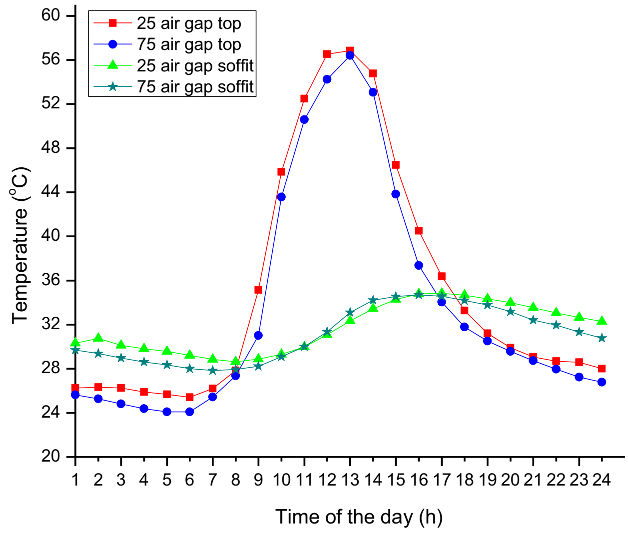

Fig. 8 Observed slab top and slab soffit temperatures of the systems with 25-mm and 75-mm air gaps

Natural air gap as a thermal insulator

Temperature readings were obtained using the Data Logger mentioned in "Using an air gap as the thermal insulator". Initially, the polystyrene insulation layer of Nandapala and Halwatura system was replaced by a 25-mm-thick unconfined air layer. The temperature readings observed on slab top and slab soffit of the model with 25-mm-thick air gap insulation are as shown in Fig. 7.

The peak slab top temperature of the model was observed to be 56.8 °C at 1300 h. The peak had transferred to the soffit within 3 h at 1600 h with a decrement factor of 0.62. These outcomes are significant figures for an insulation system as it considerably reduces the heat flow.

Then the study was extended to find out the effect of the thickness of the air gap to the thermal performance of the system. Figure 8 depicts the slab top and slab soffit temperature variations of two models with air gap thicknesses set at 25 mm and 75 mm. The result obtained for the 75-mm air gap was having a time lag of 3 h with a decrement factor of 0.62. Since the outcomes were similar to the 25-mm air gap, it was concluded that there is no effect due to the increment of the thickness of the air layer on the thermal performance.

The next attempt was made to compare the effectiveness of the 25-mm air gap with the 25-mm polystyrene (PS) insulation layer. The previously used experimental methodology

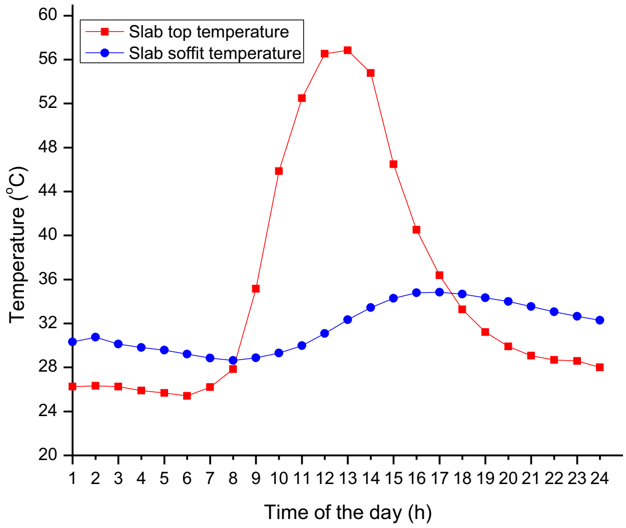

Fig. 7 Observed slab top and slab soffit temperatures of the system with 25-mm air gap

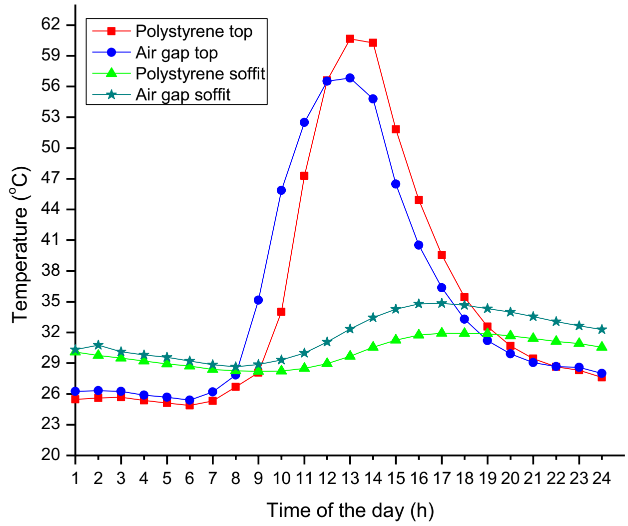

Fig. 9 Observed slab top and slab soffit temperatures of the systems with 25-mm polystyrene layer and 25-mm air gap

described in "Using an air gap as the thermal insulator" was adapted and slab soffit and top temperature readings of the models were obtained on the same day. The observations are as shown in Fig. 9.

The peak slab top temperature of the system with an air gap was observed to be less than that of polystyrene but found to have reached earlier than polystyrene. This means that the convective heat transfer is quicker in the case of the air gap. However, the heat barrier created by polystyrene was stronger than that of the air gap; hence, polystyrene was concluded to be the better insulator. The soffit temperatures shown in the same figure emphasized this fact. Anyhow, the system with the air gap has shown considerable insulation properties. Assuming that the better performance of polystyrene is due to the air confinement increasing the porosity of the insulation material, it was decided to confine the air gap to check whether there is any improvement in thermal performance.

Replacing the air gap with a transversely cut bamboo layer making an air confinement

As described in "Using a bamboo cut in the transverse direction as a thermal insulation material", a 25-mm-thick bamboo insulation panel made of transversely cut bamboo was used to substitute the 25-mm-thick air insulation layer providing an air confinement. Figure 10 shows the slab top and soffit temperature variations observed in the model constructed with a 25-mm-thick bamboo insulation layer.

The peak slab top and slab soffit temperatures of the bamboo-insulated model were observed to be 54.9 °C and 33.3 °C, respectively, with a 3-h time lag. Hence, the corresponding decrement factor was calculated to be 0.61.

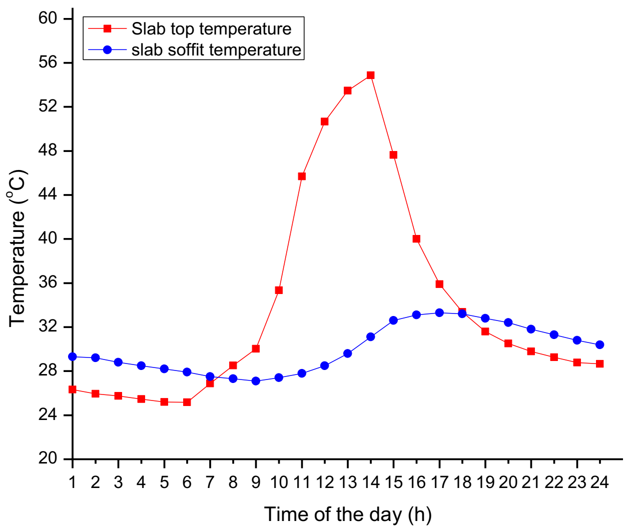

Fig. 10 Slab top and slab soffit temperature readings of the system with a 25-mm bamboo insulation layer

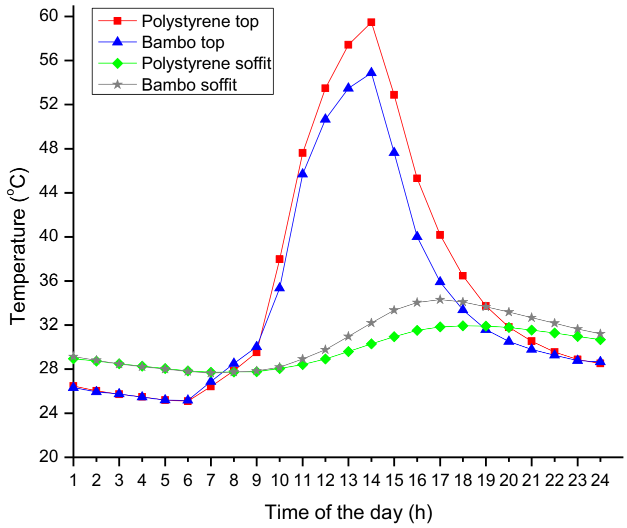

Fig. 11 Slab top and soffit temperatures of the system with a 25-mm polystyrene layer and a 25-mm bamboo layer

Nevertheless, it was necessary to analyse the thermal performance of the 25-mm bamboo insulation layer quantitatively in comparison with a 25-mm polystyrene (PS) layer. The comparison of the slab top and slab soffit temperatures between the two systems is as shown in Fig. 11.

Although the slab top temperature of the system with bamboo was lower than that of the system with polystyrene, the soffit temperatures behave conversely, similar to the case of the ventilated air gap. Considering the outcomes illustrated in Fig. 11, it is evident that polystyrene has marginally better insulation properties than bamboo. However, considering the environmental aspects, the achievement of bamboo insulation panels can be concluded to be significant.

Then the study was extended to investigate the effect of bamboo insulation layer thickness and the number of layers towards the thermal performance of the system.

Optimization of bamboo layer thickness and number of layers

Four small-scale models were constructed. Models with 25-mm-, 50-mm-, 75-mm- and two 37.5-mm-thick bamboo layers were used in the experiment. Slab top and soffit temperature readings were obtained using the experimental method mentioned in "Using an air gap as the thermal insulator".

Figures 12, 13, 14 and 15 show the slab top and soffit temperature variations observed in the models constructed with 25-mm-, 50-mm-, 75-mm- and two 37.5-mm-thick bamboo insulation layers, respectively.

Any significant difference among the slab top temperature readings of the four corresponding models was not observed.

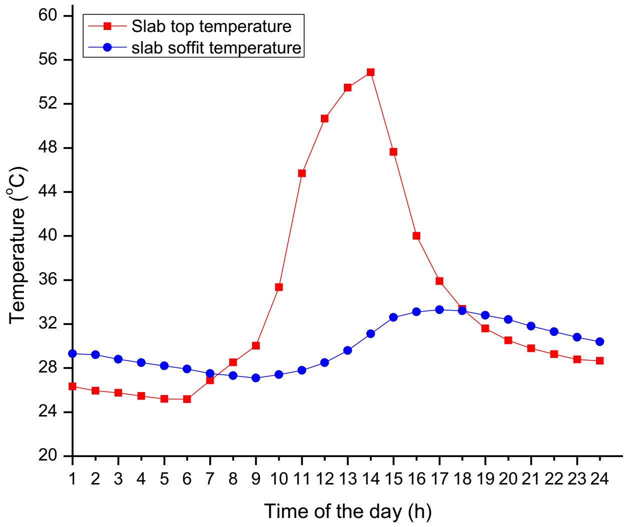

Fig. 12 Slab top and slab soffit temperature readings of the system with a 25-mm bamboo insulation layer

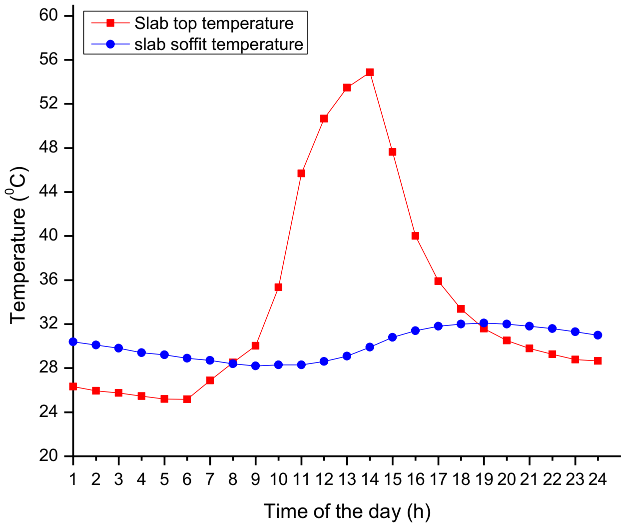

Fig. 14 Slab top and slab soffit temperature readings of the system with a 75-mm bamboo insulation layer

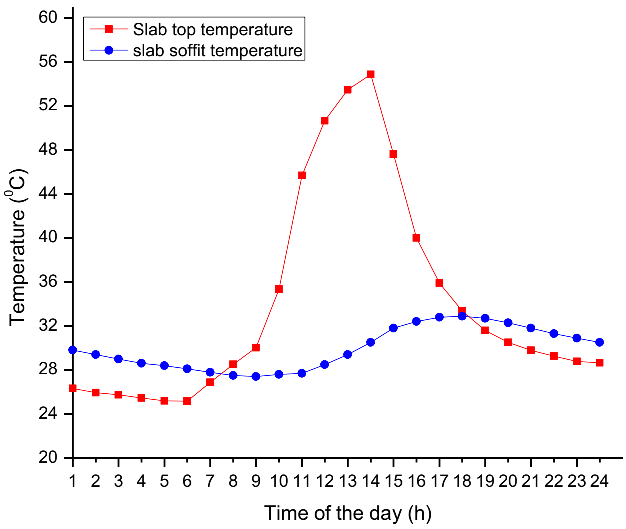

Fig. 13 Slab top and slab soffit temperature readings of the system with a 50-mm bamboo insulation layer

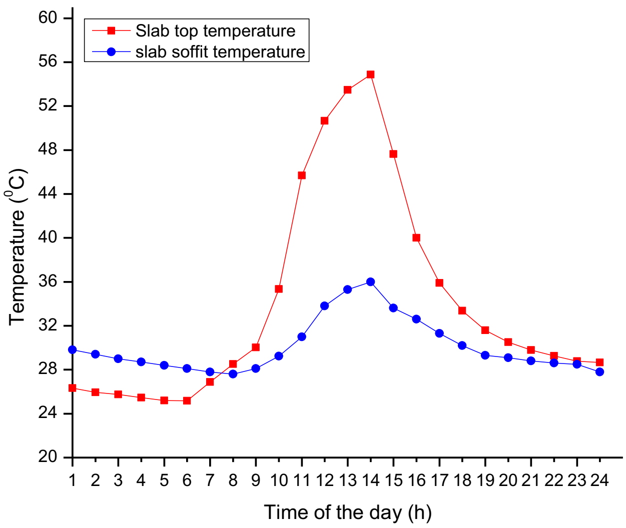

Fig. 15 Slab top and slab soffit temperature readings of the system with two 37.5-mm bamboo insulation layers

But the slab soffit temperature readings have varied in a consistent manner. They are as depicted in Fig. 16.

The peak slab top and slab soffit temperature readings, corresponding time lags and the calculated decrement factors of four tested scenarios are as listed in Table 3.

During the day of the experiment carried out, the maximum outdoor temperature was recorded as 34.6 °C. Table 3 and Fig. 16 clearly indicate that the minimum slab soffit temperature and the maximum time lag between two top temperature readings were corresponding to the model with 75-mm-thick bamboo layer. Hence, it was concluded that the increment of the height of the confined air layer improves the thermal insulation properties. Although higher thicknesses give higher thermal insulation properties, the heat transfer by convection within confined sections are prevented by own viscosity [52]. Because of that, the layer thickness cannot be increased infinitely and convective heat transfer occurs when the layer thickness becomes greater than 75 mm [52]. The slab soffit temperature difference between bamboo insulation panels of 75-mm and 25-mm-thick bamboo layers was 1.2 °C and the difference between decrement factors was 0.02. Although the least slab soffit temperature and the decrement factor was corresponding to the 75-mm-thick bamboo layer, it has consumed a three-time greater insulator thickness compared to the 25-mm bamboo layer. Because

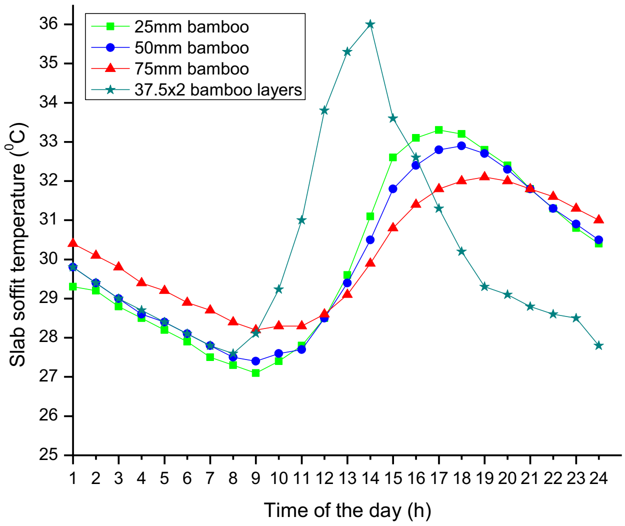

Fig. 16 Slab soffit temperature readings of the system with 25-mm-, 50-mm-, 75-mm- and two 37.5-mm-thick bamboo insulation layers

of that, 25 mm was selected as the optimum bamboo layer thickness.

When it comes to the effect of the number of layers, 37.5-mm-thick two bamboo layers were considered representing 75 mm layer thickness. Figure 16 clearly indicates that the line of the graph which represents the slab soffit temperature variation of the two 37.5-mm bamboo layer model behaves significantly different to others. In there, the maximum slab soffit temperature was 36 °C creating a decrement factor of 0.66 without any time lag. Hence, it was concluded that increment of the number of bamboo insulation layers does not significantly contribute to the enhancement of thermal performance of the system. Ultimately, it was concluded that a layer of a 25-mm-thick transversely cut bamboo insulation panel can be effectively used as the optimum insulation layer thickness of the system.

Peak heat gain reduction by bamboo insulation slab system

The ultimate objective of any thermal insulation method is lowering the heat gain/loss through the corresponding building element. Since the study is limited to tropical climatic conditions, only the heat gain reduction was considered. Heat gain reduction was calculated using the novel slab insulation system with a 25-mm-thick bamboo insulation layer and a 125-mm-thick uninsulated reinforced concrete roof slab. All the temperature readings were obtained adhering to the experimental setups described in "Using an air gap as the thermal insulator". The calculated "U" value (composite thermal conductivity) of the uninsulated slab was 3.944 W/m^2 K and the "U" value of bamboo-insulated system obtained from the computer simulation was 1.097 W/m^2 K. Graphical representation of calculated heat gain/loss values of two scenarios are as shown in Fig. 17 (corresponding calculations are given in "Appendix A").

The peak heat gain through bamboo-insulated and uninsulated slab systems was 38.51 W and 81.67 W, respectively. Figure 17 clearly indicates a significant drop in heat flow with 25-mm-thick bamboo insulation system. According to the ultimate calculation, the peak heat gain reduction due to 25-mm-thick bamboo insulation system with respect to the 125-mm-thick uninsulated slab was 53% (the calculation is given in "Appendix A"). Hence, it is evident that the novel thermally insulated roof slab

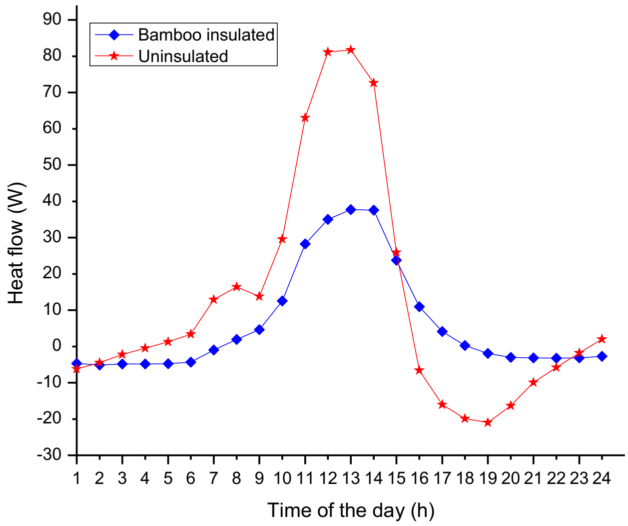

Fig. 17 Heat flow values for the two considered scenarios

Table 3 Decrement factors of tested models

Layer thickness (mm)	Slab top maximum temperature (°C)	Slab soffit maximum temperature (°C)	Time lag (h)	Decrement factor
25	54.9	33.3	3.0	0.61
50	54.9	32.9	4.0	0.60
75	54.9	32.1	5.0	0.59
2×37.5	54.9	36.0	0.0	0.66

system with 25-mm-thick bamboo layers can be used as an effective way of achieving the indoor thermal comfort.

Conclusions

Following the necessity of developing an eco-friendly insulation system, a number of experiments have been conducted with different materials and system configurations. Since the increment of void ratio of the insulator is directly proportional to the effectiveness of the thermal insulation system, the extreme condition, an air layer with 100% void ratio was tested initially. Tests on the thermal performance of an air gap as the thermal insulator indicated that no thermal performance enhancement can be obtained by increasing the air gap thickness. Since the results proved that polystyrene acts as a better thermal barrier than the unconfined air layer, an air confinement was introduced using transversely cut bamboo sections. These experiments revealed that the optimum thermal performance can be achieved through a 25-mm-thick bamboo insulation layer and there is no significant effect from the multiple bamboo layers towards the ultimate thermal performance. Since the bamboo is a highly available low-cost natural material with a rapid growth rate, it can be consumed without any risk of scarcity. Utilization of bamboo insulation system to fulfil the thermal insulation aspects assist in achieving the desired comfort levels in a much environmental friendly manner. Due to the structural arrangement with the ability to withstand any practical load on roof, the bamboo-insulated roof slab insulation system is considered as a structural sound as well as a thermally insulated eco-friendly slab insulation solution which can provide a peak heat gain reduction of 53% % under tropical climatic conditions with a decrement factor of 0.61, followed by a 3-h time lag.

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Compliance with ethical standards

Conflict of interest On behalf of all authors, the corresponding author; Madujith Sagara Chandra states that there is no conflict of interest.

Appendix A

Calculating composite thermal conductivity of Nandapala Halwatura system [53]

$$\frac{1}{K_1} = \frac{1-\emptyset}{K_{ps}} + \frac{\emptyset}{K_{con}},$$

where K_1 is the thermal conductivity of the insulation layer, $\emptyset$ is the volume fraction of concrete (3.3% in the case [17]), K_{ps} is the thermal conductivity of polystyrene (taken as 0.033 W/m K), and K_{con} is the thermal conductivity of reinforced concrete (taken as 1.7 W/m K),

$$\frac{1}{K_1} = \frac{1-3.3\%}{0.033} + \frac{3.3\%}{1.7},$$

where $K_1 = 0.034$ W/m K

Thermal resistance of the system $(R_1) = \frac{d_1}{K_1} + \frac{d_2}{K_2} + \frac{d_3}{K_3}$ (“d” is the layer thickness),

$$= \frac{0.04}{1.7} + \frac{0.025}{0.034} + \frac{0.1}{1.7} = 0.82\ \mathrm{m^2\ K/W}$$

Air-to-air resistance of the slab insulation system = $R_{top} + R_1 + R_{soffit}$

R_{top} and $R_{soffit} = 0.04\ \mathrm{m^2\ K/W}$ and $0.14\ \mathrm{m^2\ K/W}$

Air-to-air resistance of the slab insulation system = $0.04 + 0.82 + 0.14 = 1.0\ \mathrm{m^2\ K/W}$

Hence, composite thermal conductivity of the slab insulation system = $\frac{1}{1.0} = 1.0\ \mathrm{W/m^2\ K}$

Calculating thermal conductivity of uninsulated slab system

Thermal resistance of the system $(R_1) = \frac{d_1}{K_1}$ (“d” is the layer thickness),

$$= \frac{0.125}{1.7} = 0.0735\ \mathrm{m^2\ K/W}$$

Air-to-air resistance of the slab insulation system = $R_{top} + R_1 + R_{soffit}$

R_{top} and $R_{soffit} = 0.04\ \mathrm{m^2\ K/W}$ and $0.14\ \mathrm{m^2\ K/W}$

Air-to-air resistance of the slab insulation system = $0.04 + 0.0735 + 0.14 = 0.2535\ \mathrm{m^2\ K/W}$

Hence, composite thermal conductivity of uninsulated roof slab = $\frac{1}{0.2535} = 3.94\ \mathrm{W/m^2K}$

Details of the simulation model used obtain composite thermal conductivity and air-to-air resistivity of bamboo insulation system

Basic details

Plan area	1.2 m × 1.2 m
Number of stories	01
Location	Moratuwa, Sri Lanka
Latitude and longitude	6.79°N, 79.9°E
Altitude	30 m
Exposure to wind	Normal
Average monthly mean temperature	28 °C
Nearest weather station	Ratmalana, Sri Lanka

Activity details

Type of the building	Dwelling, 24/7
Occupation rate	$0.00/m^2$
Metabolic rate	Corresponds to dwellings
Household equipment	None

Construction details

Thickness of the walls	102.5 mm (half brick thick wall)
Walling material	Brick (0.51 W/m K)
Structural slab thickness	100 mm (1.7 W/m K)
Protective screed thickness	40 mm (1.7 W/m K)
Percentage of openings in E–W direction	0%
Percentage of openings in N–S direction	0%

Specimen heat flow calculation

Heat gain/loss $(W) = A \times U \times \Delta T$,where A is the area subjected to heat flow, U is the composite thermal conductivity of the system and ΔT is the temperature gradient.

Heat flow calculation of bamboo insulation system: $A = 1.2 \times 1.2 = 1.44\ \text{m}^2$, $U = 1.097\ \text{W/m}^2\ \text{K}$, and $\Delta T = 53.48\ °\text{C}–29.1\ °\text{C} = 24.38$ temperature units

Peak heat gain of bamboo insulation system $= 1.44 \times 1.097 \times 24.38 = 38.51$ W

Heat flow calculation of uninsulated slab system: $A = 1.2 \times 1.2 = 1.44\ \text{m}^2$, $U = 3.944\ \text{W/m}^2\ \text{K}$, $\Delta T = 55.45\ °\text{C}–41.07\ °\text{C} = 14.38$ temperature units

Peak heat gain of uninsulated slab system $= 1.44 \times 3.944 \times 14.38 = 81.67$ W

Heat gain reduction calculation

Peak heat gain of bamboo insulation system = 38.51 W

Peak heat gain of uninsulated slab system = 81.67 W

Peak heat gain reduction through bamboo insulation system with respect to uninsulated slab system = $\left\{1 - \left(\frac{38.5126}{81.6692}\right)\right\} \times 100\% = 52.84 \approx 53\%$

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Operational feasibility of a hybrid roof insulation system with bamboo and vegetation: An experimental study in tropical climatic conditions

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ABSTRACT

A significant portion of the global energy is consumed for creating thermally comfortable building interiors. Insulating the roof has been identified as an effective measure in addressing the issue. Bamboo-transversed is a novel roof insulation material which has proven to yield significant energy saving. This paper presents the results of an experimental study conducted to compare the Life Cycle Operational Performance of polystyrene insulation, bamboo insulation, rooftop vegetation and hybridizing vegetation with polystyrene and bamboo. Results indicated that Polystyrene is a better thermal insulator than bamboo producing 12% reduction of annual energy consumption in comparison with that of 8% of bamboo. When hybridized with rooftop vegetation, both produce similar energy savings around 13–14%. However, polystyrene produced a reduction of 5% in the 50-year Life Cycle Cost analysis, in which bamboo produced 3% while the vegetated cases producing only 2% saving. Bamboo was proven to be paying back its initial investment in 0.9 years, while the same was 1 year for polystyrene. Hybridized insulated system was proven to take 2–4 years to pay back the initial investment. Hence, it was proven that hybridizing rooftop vegetation with bamboo does not boost the operational performance sufficiently to justify its investment.

1. Introduction

The world is gradually moving towards an energy crisis [1–4]. Reducing the energy demand and creating flexibility in energy demand in order to respond to fluctuations in renewable electricity generation need to go hand-in-hand to address the issue [5]. The main source of energy in the world to date is fossil fuel, which at the current state can assuredly be considered a scarce resource [6]. Besides, its adverse effects have accelerated the rate of Global Warming and climate change, escalating the issues.The increase of the electricity demand per degree of temperature increase is proven to vary between 0.5% and 8.5% [7]. The impacts of Global Warming have its shares in diverse fields. Liu et.al. state that the total production of rice in China will decrease by 11.4% under a temperature rise of 2.0 °C, which is proven to be likely in near future in the region [8]. Further, the same rise in temperature in the same region is predicted to result in an increase of toxic pollutant loads in stormwater by 50% [9]. Numerous studies including the few mentioned here prove that Global Warming has its impacts in a variety of fields. Reducing the energy consumption plays a key role in mitigating

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Global Warming.

In this setting, it is significant to study the possible approaches to reduce the domestic energy consumption. Presently, buildings consume 30–40% of global energy consumption and around one-third of global energy consumption which by itself is alarming [10].

The amount of energy consumed for thermal comfort contributes to a significant portion of the energy utilized worldwide. It has been discovered that heating and cooling in total building energy use is very diverse with this share varying between 18% and 73% across different regions in the globe [10]. Numerous studies have been carried out on the matter, among which insulating the building envelope has found to be effective as the envelope accounts for 50–60% of total heat gain/loss in a building [11,12]. A study in Greece has shown that the application of cool roofs results to 17% reduction in the annual cooling demand [13]. Another study in Florida, USA has resulted in finding that electrical savings in the buildings averaged 19% by applying a cool reflecting coating on the roof [14]. A cool roof application in Sicily has registered a 54% reduction of the cooling energy demand [15]. An Experimental study by Alvardo et al. based on laboratory-scale prototypes has shown that a hybrid system with an insulator and a reflector on top of the roof has led to reductions in heat conduction between 65% and 88% when compared to a control prototype [16]. Two similar studies (without the rooftop reflector) in Sri Lanka have proven to achieve a heat gain reduction of more than 75% [17,18]. A different approach has been adapted by Dimoudi et al. by experimenting with a ventilated roof. The addition of the barrier keeps the insulation at a temperature 5 K lower in comparison with a typical roof, but they have not quantified the cooling load reduction potential [19]. Another case study in Italy has obtained an energy saving potential of around 50% through a simulation by adding a low energy performing block to the facade of the building [20]. Those studies can be broadly categorized as studies involved in Temperate or Mediterranean climatic conditions where both heating and cooling are required, and arid or tropical climatic conditions where only cooling is required. It is evident by these studies that insulating the building envelope yields significant energy savings and most of these studies focus on reducing the heat gain through roof, as it is the element that contributes to the maximum thermal gain inside buildings [21].

There is also a trend in inventing eco-friendly insulation materials and some of these studies have gained success to a significant extent. Banana and Polypropylene fibre [22], sheep waste wool [23], corn cob [24,25], cotton stalks [26], date palm [27,28], cellulose [29], oil palm [30], durian [31], rice [32], pineapple leaves [33] and straw bale [34,35] have performed significantly well an insulators. In addition, Wang et al. have developed an inorganic insulation material from pitchstone, and Mandili et al, have experimented with waste paper as an insulation material, of which they claim to have succeded [36]. Megri et al. has tried plastic waste as an insulator, but proven to be less effective than traditional insulation materials. However, they conclude that the obtained results are ‘interesting’ and is feasible considering the environmental benefits [37,38] Their worth is enhanced considering the positive impact on the environment.

Rooftop vegetation is another alternative that is often used in the modern context instead of insulation. It has a vast spectrum of advantages from the perceptions of environmental, social and financial [39–41]. The energy saving potential is the key benefit on which most of the literature is available. A study in Japan has shown that Rooftop lawn reduced peak air temperature by 3–4 °C in summer [42]. A study in Greece has resulted an indoor temperature reduction of 0.6 °C [43]. In Singapore, a country with tropical climatic conditions, A maximum heat reduction of more than 60% has been obtained [44]. In Hong Kong, the Green roofs have yielded 75% lower heat storage than bare roofs [45]. A study in Taiwan presents a decrease in ambient air temperature by 0.3 °C in winter, 0.5 °C in spring, and 1.2 °C in summer [46].

Despite the advantages, such systems have not been gained the acclaim as intended due to their drawbacks such as the requirement of additional finances, durability concerns and probable structural enfeebling [47].

This study attempts to sort those issues out in tropical conditions. In this context, a system has been developed in Sri Lanka by Halwatura & Jayasinghe [48] with a significant degree of energy saving, but lacks on durability. Consequently, Nandapala & Halwatura have developed a new system which they claim have been proven durable [49].

In the subsequent process of making the system ‘Greener’ another study has been carried out to replace the polystyrene layer which they had used as the insulator with a bamboo-transversed layer [50–52]. However, its thermal performance has not been proven substantial in comparison with traditional insulators. But they have concluded that it is worth considering based on an environmental standpoint.

Hybridizing bamboo with a rooftop vegetation layer has the potential of significant energy savings among other mentioned advantages. This paper presents a study on a comparison of the operational performance of standalone polystyrene (traditional insulation material), standalone bamboo and when those materials are hybridized with a layer of rooftop vegetation.

2. Objectives of the study

The objective of this study is to investigate the operational feasibility of bamboo-transversed insulation when hybridized with rooftop vegetation. Here, we compare the Life Cycle operational feasibility of standalone bamboo insulation with standalone traditional insulation in the form of polystyrene and those hybridized with a rooftop vegetation layer. We used an additional experimental setup without any form of insulation and another with a standalone vegetation layer to fortify the conclusions.

We calculated the annual energy consumption, Life Cycle Cost for a lifespan of 50 years and the discounted payback period of each of the cases and performed a comparison in the process of comparing the operational feasibility.

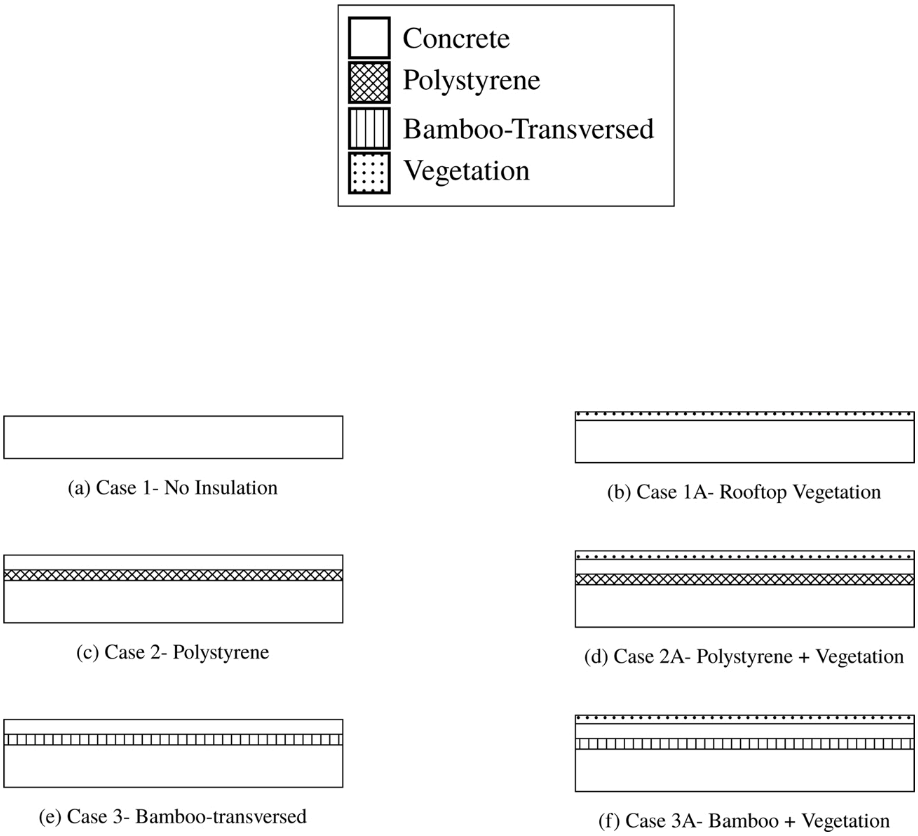
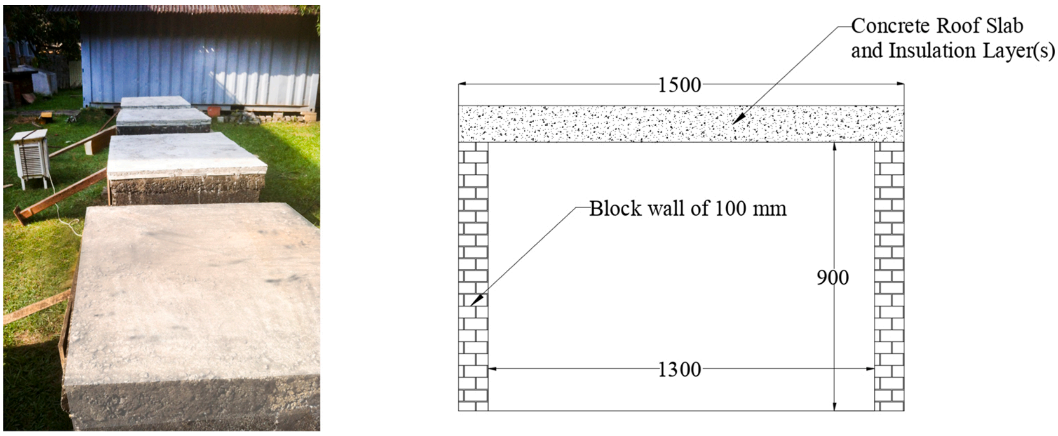


Fig. 1. Insulation cases that the experiments were conducted.



(a) A Photo of the Small Scale Physical Models Cast in Stage 1

(b) Cross-section of the Small Scale Physical Models Cast

Fig. 2. Small scale physical models.

3. Methodology

3.1. General

We used a three-step process in order to compare the six systems stated in Section 2: small scale physical model testing, calibrated computer simulations and a discounted cash flow analysis. GL820 midi data logger was used for recording temperatures and DesignBuilder v6 was used for computer simulations. Sri Lankan market rates, converted to United States Dollars (USD) at an exchange rate of 190/= Sri Lankan Rupees per dollar were used in discounted cash flow analysis.

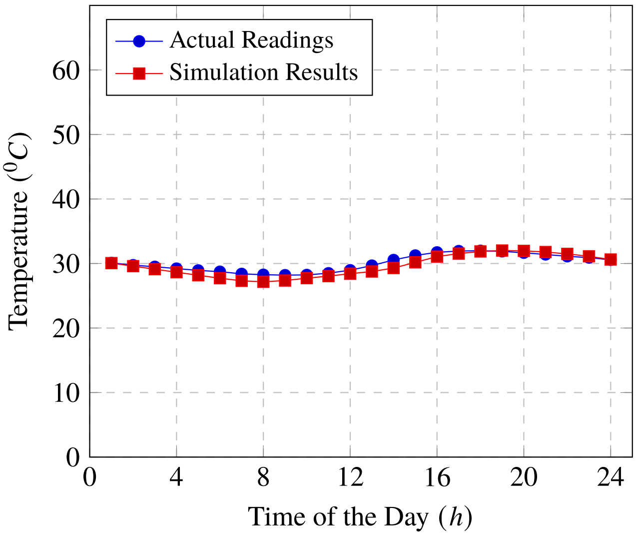


Fig. 3. Actual readings and the simulated results of slab soffit in the calibrated model for the experiments conducted in stage 1.

3.2. Small scale physical model testing

Six physical models were cast in April, which is one of the two months that Sri Lanka has extreme temperatures along with August/ September, to obtain the optimum performance of insulators. Following are the insulation cases cast (refer Fig. 1);

- Case 1 – Uninsulated slab as the control experiment (Fig. 1a)
- Case 2 – Polystyrene Insulation layer of 25 mm in thickness and a screed concrete of 40 mm (Fig. 1c)
- Case 3 – Bamboo-transversed insulation layer of 25 mm in thickness and a screed concrete of 40 mm (Fig. 1e)
- Case 1A – Vegetation layer of 65 mm in thickness (Fig. 1b)
- Case 2A – Polystyrene layer of 25 mm in thickness, screed layer of 40 mm and a vegetation layer of 65 mm (Fig. 1d)
- Case 3A – Bamboo-transversed layer of 25 mm in thickness, screed layer of 40 mm and a vegetation layer of 65 mm (Fig. 1f)

The temperature measurements were taken in three stages, with each having an overlapping case to another. Fig. 2a shows a photograph of the small scale models cast in Stage 1 and Fig. 2b shows a cross section of the models. Slab-top and slab-soffit temperatures, inside air temperatures and outside ambient temperatures were measured in each of the cases. However, only the top and soffit surface temperatures were used in the calibration process as the effect of thermal mass had to be minimized since the results were to be comparable with real-scale applications. A minimum of two probes were used on a single surface to enhance the accuracy. Each stage was measured for a minimum of five days at ten-minute intervals and hourly average values were calculated after removing the outliers. The differences observed in ambient conditions between three stages were normalized by calibrated computer simulations.

3.3. Calibrated computer simulations

Computer simulations were performed with Design Builder v6 software package in two stages: Small scale physical models and a real scale model. The calibration of the small scale physical models were performed based on the experimental data obtained as mentioned in the previous section, and that of real scale model was performed by manual calculations as per the method prescribed in CLTD/SCL/CLF method for cooling load calculation.

First four cases of the small scale physical models stated in the Methodology (Case 1, Case 2, Case 3 and Case 1A) were modelled and compared with the observed results. The comparison was performed for slab-top and slab-soffit surface temperatures instead of internal air temperature to minimize the effect of thermal mass. The graph of the actual readings and the simulation results of the slab-soffit of the small scale physical model testing is shown in Fig. 3.

Two criteria were maintained for a satisfiable calibration;

1. The time of the peak temperature was maintained the same in both observed and simulated curves.
2. Each temperature value corresponding to a time in the simulated curve was maintained to be within 5% of the observed curve.

Having found the combined thermal conductivity values (U-values in W m^{-2} K^{-1}) by the procedure, layer thermal conductivity values (K-values in W m^{-1} K^{-1}) of all insulation layers were manually calculated. A sample calculation is given in Appendix A. Hence, the last two cases in Methodology (Case 2A and Case 3A) were used for validating the model maintaining the same calibration criteria. This iterative procedure was adapted until all models were sufficiently calibrated and validated.

A computer simulation was performed on a real-scale model with the characteristics provided in a previous study in similar

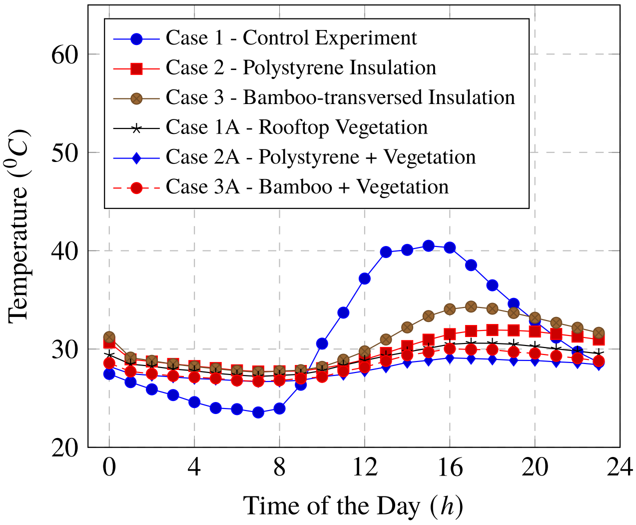


Fig. 4. Normalized average slab-soffit temperatures in a 24-h cycle.

Table 1
Air-to-air thermal conductivity values of the considered cases mentioned in Section 3.2.

Case	Type of insulation	Air-to-air U-value (W m^{-2} K^{-1})
1	No insulation	4.68
2	Polystyrene	1.03
3	Bamboo-transversed	2.48
1A	Rooftop Vegetation	0.98
2A	Polystyrene + Vegetation	0.56
3A	Bamboo-transversed + Vegetation	0.82

conditions [18] to analyze the energy saving potential of the insulation materials of interest in real-life conditions (the details of the real-scale model are given in Appendix). This was calibrated and validated by manual calculations as per the method prescribed in CLTD/SCL/CLF method for cooling load calculation [53]. A summary of the calculations for the calibration is presented in Appendix C. The deviation of the cooling load calculated manually and by the software was 3%, which was decided to be sufficient. Then the annual energy consumption to keep the operative temperature at 26 °C for each case was extracted from the model.

3.4. Discounted cash flow analysis

The Life Cycle Cost for a lifespan of 50 years and the discounted payback period of each case were calculated with a discounted cash flow analysis. Initial costs and annual maintenance costs were obtained by the market rates in Sri Lanka. The details of the assumed costs are presented in Appendix D. Annual energy consumption values were directly obtained by the calibrated model simulations, and the Life Cycle Costs (Present Values of all cost elements) were calculated by Eq. (1), and subsequent payback periods were calculated by Eq. (2) [54]. Finally, a sensitivity analysis was performed to study the effect of change in discounting factor on the results.

$$\text{Present value of costs across the lifespan (PV)} = \sum_{j=1}^{n} \frac{F_j}{(1+i)^j} \tag{1}$$

$$\text{Discounted payback period (T)} = \min \left\{ k : \sum_{j=1}^{k} \frac{P_j}{(1+i)^j} \geq 0 \right\} \tag{2}$$

Where, P_j = Present Value of the cost in j^{th} year, F = Future Value of Money in j^{th} year, i = Discounting Factor/Interest Rate, n = Project Life

4. Results

4.1. Results of the small scale physical model testing

The normalized slab-soffit temperatures of the systems are plotted in Fig. 4. It evidently indicates that there is an effect of vegetation on the thermal performance of the system in a 24-h cycle. Furthermore, it consolidates the observations made by Chandra et al. [55] that bamboo alone does not produce an equivalent thermal performance as polystyrene does. Unsurprisingly, Case 2A, the system

Table 2
Thermal conductivity values derived from the results of the computer models.

Insulation material	Thermal conductivity (W m^{-1} K^{-1})
Concrete	1.7 [48]
Polystyrene	0.034
Bamboo-transversed	0.15
Rooftop Vegetation	0.08

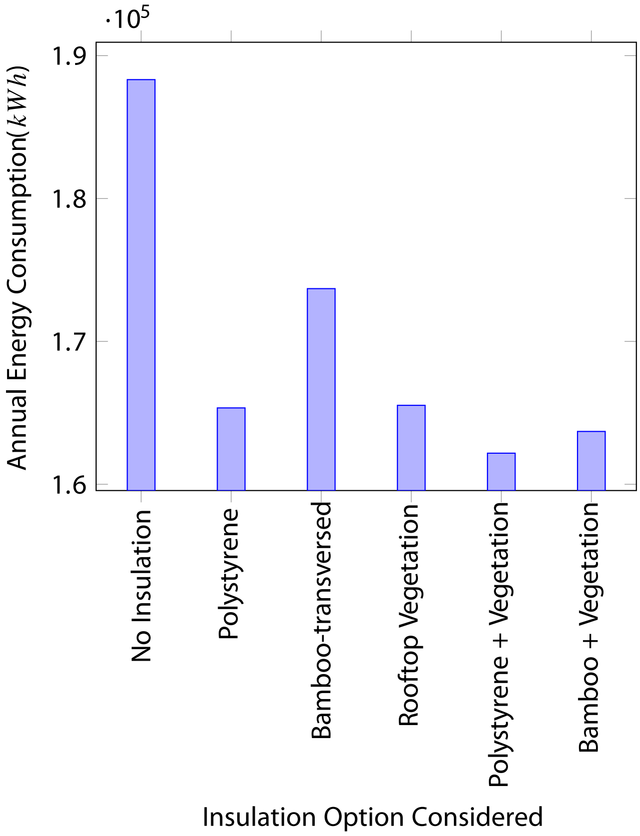


Fig. 5. Annual energy consumption obtained by calibrated computer simulations.

with vegetation coupled with polystyrene insulation, produced the best thermal performance of all cases tested, maintaining an almost constant temperature of 28 °C at the soffit of the slab.

4.2. Results of the calibrated computer simulations

The Air-to-air thermal conductivity (U) values with the roof slabs were picked out from the computer simulations of the small-scale models. The obtained *U*-values are as tabulated in Table 1. These values indicate that there should be significant energy savings for all insulation cases in comparison with a roof slab without any insulation. Furthermore, hybridizing with vegetation should yield some degree of enhancement in thermal aspects. Then each system was evaluated as a set of layers perpendicular to the direction of heat flow and the thermal conductivity (K) values were derived manually. A sample *U*-value calculation is presented in Appendix A.

The results of the subsequent compilation of literature details, model calibration, model validation, and reverse calculation of the thermal conductivity values are tabulated in Table 2. The values corresponding to concrete and polystyrene are consistent with the literature [18,49], and 0.15 W m^{-1} K^{-1} for bamboo-transversed and 0.08 W m^{-1} K^{-1} for rooftop vegetation were verified by the process of model validation.

The annual energy consumption of the real-scale model, of which the details are presented in B, were calculated by computer simulation and are presented in Fig. 5. Standalone polystyrene insulation and rooftop vegetation have produced a 12% annual energy saving, whereas the hybrid system with rooftop vegetation has increased the same to 14%. However, the 8% of the energy saving of bamboo insulation, which itself is significant in real-life conditions, has spiked to 13% when hybridized with rooftop vegetation.

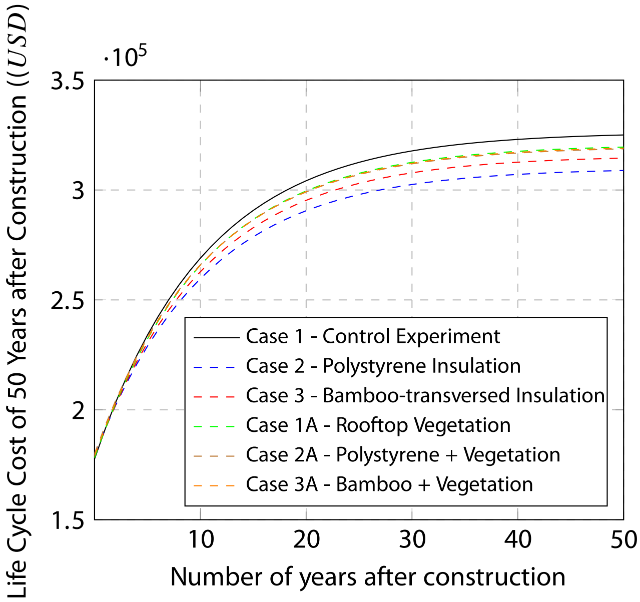


Fig. 6. Present value of costs across the lifespan of the compared systems for a period of 50 years and a discounting factor of 10%.

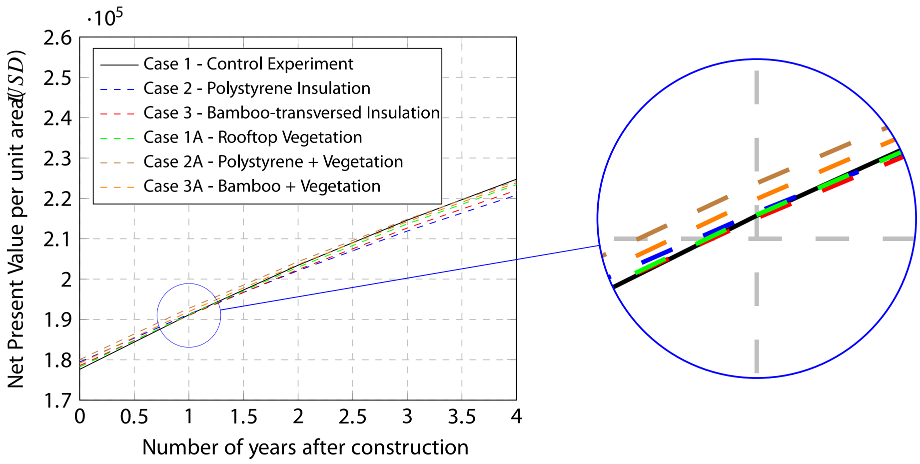


Fig. 7. Present value of the compared systems in the first four years for a discounting factor of 10% and a magnified around one-year mark.

Table 3
Calculated discounted payback periods of the insulation cases considered.

Case	Type of insulation	Discounted payback period (Years)
2	Polystyrene	1.0
3	Bamboo-transversed	0.9
1A	Rooftop Vegetation	1.1
2A	Polystyrene + Vegetation	3.4
3A	Bamboo-transversed + Vegetation	2.3

4.3. Results of the discounted cash flow analysis

Similar previous studies have compared the Life Cycle Cost values for different insulation cases for discrete values of lifespan [18, 56]. In this paper, we evaluate the variation of the Life Cycle Cost continuously up to 50 years from construction to study its behaviour with respect to time while comparing with previous findings. The calculated Present Values of costs across the lifespan of each of the insulation cases of interest corresponding to a discounting factor of 10% are depicted in Fig. 6.

At the outset, the figure indicates that Present Values of all the insulated cases fall below that of the control experiment, deducing that NPV is positive in all insulated options, and hence, all these options are financially viable in comparison with the control experiment which is the uninsulated slab.

Furthermore, it indicates that standalone polystyrene insulation is the best of all considered options in terms of Life Cycle Cost,

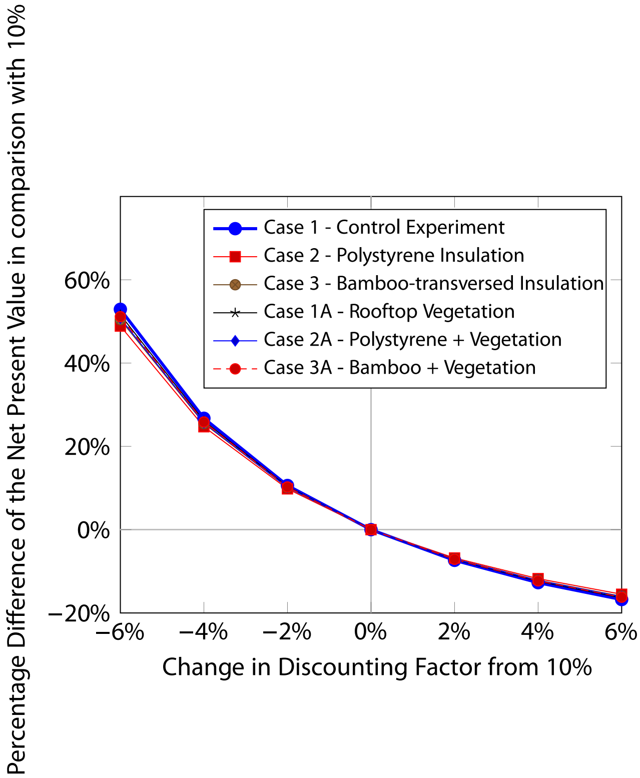


Fig. 8. Sensitivity of the discounting factor to the net present value in 50 years.

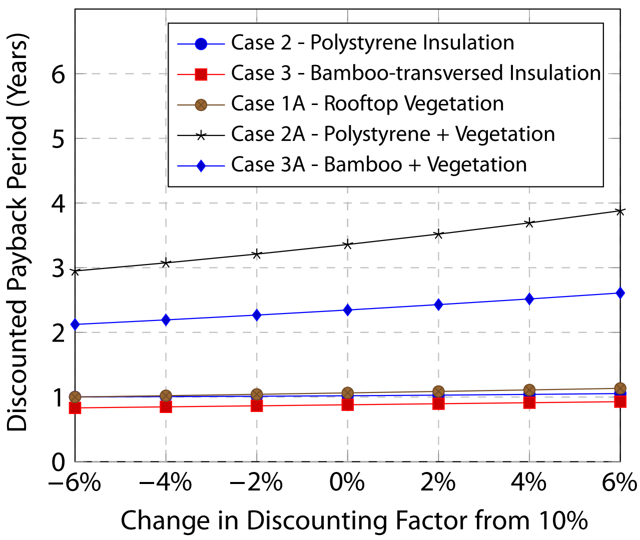


Fig. 9. Sensitivity of the discounting factor to the discounted payback period [57].

producing a 5% reduction at the end of the lifespan. Noteworthy, Bamboo-transversed insulation performs better than the systems with vegetation, resulting in deducing that the investment on hybridizing with vegetation is not operationally feasible in comparison in the long run. Even though it results in additional energy saving, the maintenance cost surpasses the financial gain of the energy cost saving.

Furthermore, all cases with rooftop vegetation have resulted in approximately 2% of Life Cycle Cost savings, indicating that whether it stays alone or hybridized with another insulation, it performs the same in financial aspects in the long run.

In addition, we performed a discounted payback period calculation to obtain another perception on the operational performance of the systems.

A zoomed graph of the Life Cycle Cost of the first four years of construction is shown in Fig. 7. It indicates at a glance that all insulation options have paid back their initial investment within the first four years of its construction. The calculated discounted payback periods of all considered cases are presented in Table 3.

The results suggest that Bamboo-transversed insulation performs the best in the considered cases in the discounted payback period.

Table 4
Summary of the results derived in the study.

Insulation case	*U*-value (W m^{-2} K^{-1})	Annual energy consumption reduction	Life Cycle Cost reduction	Discounted payback period (years)
No insulation	4.68	–	–	–
Polystyrene	1.03	12%	5%	1.0
Bamboo-transversed	2.48	8%	3%	0.9
Rooftop Vegetation	0.98	12%	2%	1.1
Polystyrene + Vegetation	0.56	14%	2%	3.4
Bamboo + Vegetation	0.82	13%	2%	2.3

However, the other two standalone insulation options, polystyrene and rooftop vegetation, closely follow the values, both hovering around the one-year mark. Case 2A and Case 3A, where the rooftop vegetation is hybridized with another insulation, understandably takes a significant amount of time to recover in comparison, but not as significant to deem the option to be operationally incompetent as a thermal insulator.

Finally, we performed a sensitivity analysis to study the effect of the variation in the discounting factor on the final results. Fig. 8 shows the effect at the end of 50 years. The graph deduces that the Life Cycle Cost is highly sensitive to the low values of the discounting factor, however, it can be concluded that the effect of which is insignificant in the context of this study since it affects all cases in an almost identical manner.

Similarly, the effect of the variation in the discounting factor on the discounted payback period is presented in Fig. 9. There is a positive correlation of the two variables in all considered cases, but can be considered insignificant in the macro level of this study as the intention of this study is to compare the insulation options.

5. Discussion and conclusion

The summary of the performed analyses are presented in Table 4. Comparing the annual energy consumption indicates that bamboo-transversed is a good enough insulator, but not as effective as polystyrene nor rooftop vegetation. However, hybridizing with rooftop vegetation spikes the reduction in energy consumption by an additional 5% from the original 8%. In contrast, polystyrene standing alone produces a 12% reduction in annual energy consumption, but the hybridizing process only adds 2% for the value. Hence, it is apparent that the effect of hybridizing is high in bamboo.

In contrast, the Life Cycle Cost reduction for a discounting factor of 10% and a lifespan of 50 years indicates that polystyrene insulation performs the best, and Bamboo-transversed lags behind but performs better than all cases with vegetation. The findings deduce that even though the initial investment on rooftop vegetation can be justified in comparison with a case with no insulation, its operational benefit is neither as significant as polystyrene nor bamboo-transversed in the long run.

Bamboo has been proven to payback its initial investment in the shortest time while rooftop vegetation and polystyrene insulation closely follow, all hovering around one-year mark. However, when insulation is coupled with rooftop vegetation, it takes longer to payback in comparison, but does within 2–4 years, which itself is a significant achievement. It should be noted that these values do not stand inline with the literature [58]. This is due to the higher degree of thermal performance in extremely hot and humid climate conditions, and the relatively low additional construction cost in the context of the experiment.

However, these observations should be noted with some remarks. The experiments were performed with a particular extensive rooftop vegetation, and therefore the effects of parameters such as the degree of saturation and leaf area index were not considered here. Changing the layer thickness and trying out a different type of vegetation layer could alter the findings, but with the results obtained in the study, the chances of which are marginal.

Another noteworthy remark is that this study focused only on the operational energy and financial aspects of insulation. Hence, polystyrene was proven to be the most effective of the considered options. A study on the embodied energy is needed to be carried on to make an overall final comment. Furthermore, the ecological aspects of the cases have not been studied in this paper, and a separate study on that is worthy to be considered.

In addition, it should be noted that the experimental measurements have been recorded for a few days, and the results were extrapolated over a period of an year for comparison purposes. Here, the weather file of the model has been inspected and periodic steady-state external temperatures calculated using maximum and minimum design summer weather conditions. It would be more accurate if the experiment itself were carried out over a year, however, the effect of which was considered negligible since the main intention of this study was to compare the operation feasibility and the same weather file has been used across all considered cases.

Finally, it can be concluded that hybridizing bamboo with rooftop vegetation boosts the thermal performance to a higher degree in comparison with the same of polystyrene. However, there was evidently poor performance of the systems with rooftop vegetation in Life Cycle Cost due to the continuous maintenance costs. Nevertheless, the initial investments of all systems were paid back plentifully within its lifespan, with standalone insulation cases performing exceptionally.

Hence, it can be concluded that even though any form of roof insulation is feasible in energy saving potential and financial feasibility. However, hybridizing rooftop vegetation with another insulation material does not boost the operational performance sufficiently to justify its investment.

Table A.5
Surface resistances of roof slab are shown in Table A.5.

Location	Symbol	Surface resistance
Top surface	R_T	0.04 [59]
Soffit	R_S	0.1 [59]
Insulation system	R_I	0.034 [49]

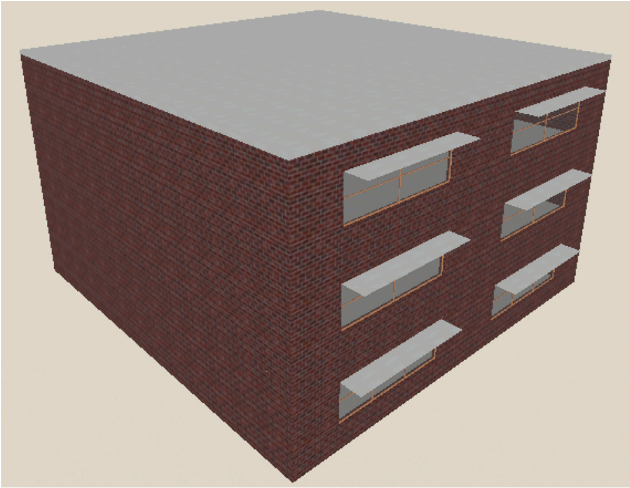


Fig. B.10. Simulated model of the actual scale model.

Declaration of interests

The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

Declaration of Competing Interest

The authors report no declarations of interest.

Appendix A. Sample *U*-value calculation

$$\text{Thermal resistance of the system with polystyrene} = \frac{T_1}{K_1} + \frac{T_2}{K_2} + \frac{T_3}{K_3}; (T_i - \text{Thickness of the layer})$$

$$= \frac{0.04}{1.7} + \frac{0.025}{0.034} + \frac{0.125}{1.7}; \text{From Table A.5}$$

$$= 0.832\,\mathrm{m^2\,K\,W^{-1}}$$

$$\text{Air-to-air resistance of the new system} = R_T + R_I + R_S$$

$$= 0.04 + 0.832 + 0.1$$

$$= 0.972\,\mathrm{m^2\,K\,W^{-1}}$$

$$\text{Hence, the composite conductivity of the newly designed system} = \frac{1}{0.972}$$

$$= 1.028\,\mathrm{W\,m^{-2}\,K^{-1}}$$

Appendix B. Details of the computer model

The simulated model is shown in Fig. B.10.

Plan area	$15\,m \times 15\,m$
Number of stories	03
Location	Moratuwa, Sri Lanka
Latitude	6.79^0N
Longitude	79.9^0E
Altitude	30 m
Exposure to wind	Normal
Average monthly mean temperature	28°C
Nearest weather station	Ratmalana, Sri Lanka
Type of the building	Office
Occupancy rate	$0.1/m^2$
Metabolic rate	Corresponds to light office work
Degree of clothing	Summer clothing
Target illuminance	400 lux
Energy generation by equipment	$10\,W/m^2$
Thickness of the roof slab	125 mm
Thickness of the intermediate slabs	125 mm
Walling material	Brick
Thickness of walls	225 mm
Percentage of openings in E-W direction	0%
Percentage of openings in N-S direction	30%
Type of openings	Glazed windows with 1m-overhang

Other than these basic details, following model conditions were used.

- Periodic steady-state external temperatures calculated using maximum and minimum design summer weather conditions.
- Wind effect has been neglected for cooling load comparison purposes.
- The external surfaces below the ground plane are considered adjacent to the ground and external surfaces above the ground plane are considered adjacent to outside conditions.
- Internal walls and floors were considered adiabatic.
- All layers (including the rooftop vegetation layer) were considered homogeneous.

Appendix C. Manual cooling load calculation by CLTD/SCL/CLF method for actual scale model calibration

Calculations are based on ASHRAE handbook 1997 [53]. The building was modelled without equipment nor appliances for calibration purposes. Calculations have been performed for the building with bamboo-transversed insulation for the roof slab.

Abbreviations used in the calculations;

$U-$	Thermal conductivity of the layer
$A-$	Area normal to the direction of the heat flow
CLTD−	Cooling load temperature difference
SC	Shading coefficient
SCL	Solar cooling load factor
t_b	Temperature outside
t_{rc}	Temperature inside
N	Number of people in space
CLF	Cooling load factor
W	Wattage of lights
F_{ul}	Lighting use factor
F_{sa}	Special allowance factor

<u>Heat gain through roof and walls</u>

$$\text{heat gain,}\quad q = U \times A \times \text{CLTD} \tag{C.1}$$

Table D.6
Cost values considered for Life Cycle Cost analysis.

Cost element	Case 1	Case 2	Case 3	Case 1A	Case 2A	Case 3A
Initial cost (USD/m^2)	263	271	267	265	273	269
Maintenance cost (USD/m^2/year)	0	0	0	2	2	2
Cost for cooling (USD/m^2/year)	22.03	19.34	20.31	19.36	18.97	19.15

Heat gain through roof $= 2.477 \times 225 \times 47$
$= 26,194.28\,W$

similarly,
Heat gain through North wall $= 2.3 \times 94.5 \times 11$
$= 2390.85\,W$

Heat gain through East wall $= 2.3 \times 135 \times 18$
$= 5589\,W$

Heat gain through South wall $= 2.3 \times 94.5 \times 16$
$= 3477.6\,W$

Heat gain through West wall $= 2.3 \times 135 \times 22$
$= 6831\,W$

∴Total heat gain through roof and walls $= 44,482.73\,\mathrm{W}$

Heat gain through windows

$$\text{heat gain,}\quad q = A \times (\mathrm{SC}) \times (\mathrm{SCL}) \tag{C.2}$$

Heat gain through windows in the North wall $= 40.5 \times 0.55 \times 110$
$= 2450.25\,W$

Heat gain through windows in the South wall $= 40.5 \times 0.55 \times 274$
$= 6103.35\,W$

∴Total heat gain through windows $= 8553.6\,\mathrm{W}$

Heat gain by the occupants

$$\text{Sensible heat gain,}\quad q = N \times \text{sensible heat gain per person} \times (\mathrm{CLF}) \tag{C.3}$$

$$\text{Latent heat gain,}\quad q = N \times \text{latent heat gain per person} \tag{C.4}$$

Total number of occupants $= 0.1 \times 225 \times 3$
$= 67.5$

∴Sensible heat gain $= 67.5 \times 75 \times 1$
$= 5062.5\,W$

Latent heat gain $= 67.5 \times 55$
$= 3712.5\,W$

∴Total heat gain by the occupants $= 8775\,\mathrm{W}$

Heat gain by lighting

$$\text{Heat gain by lighting,}\quad q = W \times F_{ul} \times F_{sa} \times (\mathrm{CLF}) \tag{C.5}$$

Assumed power intensity of lighting $= 20\,\mathrm{W/m^2}$
∴Heat gain by lighting $= (20 \times 2 \times 225) \times 1 \times 1 \times 1$
$= 13,500\,\mathrm{W}$

TotalManuallyCalculatedCoolingLoadRequirementoftheBuilding $= 75.31\,\mathrm{kW}$
TheCorrespondingValueProducedbyComputerSimulation $= 73\,\mathrm{kW}$
PercentageDifferenceinthesaidtwomethods $= 3.1\%$

Appendix D. Cost values considered for Life Cycle Cost analysis

Cost Values considered for Life Cycle Cost Analysis are given in Table D.6. Following remarks should be noted along with the table.

- All the calculations of the rates have been performed in Sri Lankan Rupees (LKR) and converted to USD with an exchange rate of LKR 190.00 for 1 USD.

- The initial costs and maintenance costs were calculated based on the Sri Lankan market rates before the pandemic as price fluctuations were too high during the pandemic.
- Following values were taken for calculating the values on table.
  –Superstructure cost is LKR 50,000 per m^2. (This value does not affect the final conclusions since it was taken as a constant in all cases)
  –Concreting cost is LKR 44,605 per cube. Hence, for the required thickness in this case, a value of LKR 630.46 per m^2 was deduced.
  –Polystyrene cost is LKR 900 per m^2.
  –Vegetation cost is LKR 300 per m^2.
  –Bamboo processing cost is LKR 150 m^2.
  –Electricity cost is LKR 15 per kWh (assuming the rate of a commercial building).

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2.3

Research publications in non-referred journals

2.3(1)

Research publications in non-referred journals

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Points are not claimed under this section

2.4

Presentations at conferences, meetings of professional associations etc.

2.4.1

Published as Full Papers

2.4.1(1)

Kasun Nandapala, Madujith Sagara Chandra, R.U. Halwatura: Effectiveness of A Discretely Supported Slab Insulation System in Terms of Thermal Performance. 11th FARU International Research Conference, Light House Hotel, Galle, Sri Lanka, 07/12/2018

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FARU 2018 - PROCEEDINGS

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The peer reviewed and accepted research papers of the conference are included in this volume

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EFFECTIVENESS OF A DISCRETELY SUPPORTED SLAB INSULATION SYSTEM IN TERMS OF THERMAL PERFORMANCE

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Abstract
One of the main issues of the thermal discomfort inside buildings is heat gain from building envelope. As a remedy, active cooling solutions such as air conditioners are commonly used. But that can never be admired owing to the contribution of excessive energy usage and environmental pollution. Hence, passive cooling solutions such as building thermal insulation can be taken as a fruitful solution. Since about 70% of heat gain of buildings occur through roofs, thermal insulation of roofs takes a prominent place in the aforesaid matter. As a result of rapid urbanization and population growth, the amount of usable land for building constructions is very low and the constructions have to be done on a very limited space. There, flat concrete roofs provide additional working spaces and the possibility of future vertical developments with other benefits such as extra robustness and the cyclonic resistance to the structures. Anyhow, utilization of flat concrete roofs is unpopular due to the thermal discomfort in the immediate space beneath. Addressing this drawback of ordinary flat concrete roofs, a new roof slab insulation system introduced having the capability of achieving more than 75% of heat gain reduction. Thermal performance comparison between the novel system and existing roof slabs confirmed the effectiveness of the new system. Further, 50mm thick vegetation was added on top of the novel slab system and thermal performance was compared. Results showed 20% of peak cooling load reduction from new slab system and 21% of peak cooling load reduction in a summer day under tropical conditions when it was vegetated.

Keywords: *Roof slab insulation, Thermal Comfort, Cooling Load, Thermal Insulation, Vegetated slabs*

1. Introduction

The burning issue, global warmth has affected every nook and corner of the globe (Miezis, Zvaigznitis, Stancioff, & Soeftestad, 2016) and it has negatively affected the thermal comfort inside buildings. Hence, a number of researches are being carried out for finding long lasting solutions for the matter. Recent studies show that, if no necessary steps are taken to reduce the emission of CO_2 and other greenhouse gasses (GHG) to the atmosphere, the average surface temperature of the earth will rise about 1.1 ^{o}C- 6.4 ^{o}C by the end of 2100 (Aditya et al., 2017). On the other hand, due to the adverse climatic changes the severity and the intensity of natural disasters such as cyclones, snow melting, floods and droughts will be increased (Vázquez Rowe, Kahhat, & Lorenzo-Toja, 2017).

In many cases, active cooling solutions such as air conditioners are commonly used to maintain the internal thermal comfort of buildings. But that practice can never be encouraged owing to the contribution of excessive energy usage and environmental pollution. One of the best solutions to overcome this thermal comfort issue is admitting passive cooling techniques which focus on reducing heat gain/loss of buildings to enhance the indoor thermal comfort through a way of less energy consumption (Kamal, 2012). In there, building thermal insulation plays a major role. Though this consumes additional initial investment, it may be paid back within a reasonable time span (Dwaikat & Ali, 2018; Robati, McCarthy, & Kokogiannakis, 2018; Sterner, 2000). One of the main ways of increasing internal temperature of buildings is solar heat gain through the building envelope. Since about 70% of total heat gain of buildings occur through roofs (Vijaykumar, Srinivasan, & Dhandapani, 2007) thermal insulation of roofs takes a major part in thermal insulation of buildings.
When the aforesaid cyclonic effects are considered, having flat concrete roofs instead of ordinary roofs provide extra robustness to the structure due to its self-weight (Halwatura & Jayasinghe, 2009). Further, having flat concrete roofs will provide extra working space as well as the easy provision of

future vertical developments addressing the scarcity of usable lands for constructions (K Nandapala & Halwatura, 2017; Kasun Nandapala & Halwatura, 2016).

When the roof slab is heated due to the direct exposure of sunlight, the immediate space beneath becomes thermally uncomfortable. Thus, lower degree of thermal comfort of ordinary flat concrete roofs has affected the less popularity of them (Halwatura & Nandapala, 2014).

There are several techniques used in terms of roof thermal insulation, such as applying cool paints (C. Romeo and M. Zinzi, 2013), using a variety of insulation materials in roofing (K. Manohar, 2012) and using rooftop vegetation (S. W. Tsang and C. Y. Jim, 2011). As a fruitful substitution for those systems, a novel roof slab insulation system was introduced addressing both issues, thermal discomfort inside buildings and cyclonic effect. In this study, the thermal performance of the newly introduced roof slab insulation system will be compared with existing flat concrete roofs. Further, the thermal performance of the novel slab insulation system under a 50mm thick vegetation layer on top of the slab will be investigated and the fruitfulness of the innovation will be proved.

2. Objectives

The ultimate objective of the study is to check the effective thermal performance of novel roof slab insulation system. The specific objectives are;

1. To compare the thermal performance of new roof slab insulation system with existing flat concrete roofs.
2. To check the thermal performance of novel system with and without a vegetation layer
3. To find the peak cooling load reduction which can be achieved by the newly designed system with and without a vegetation layer

3. Thermal performance comparison between new roof slab insulation system, existing flat concrete roof and vegetated roof slab

3.1. METHODOLOGY ADAPTED

Small-scale physical model testing was used to fulfil the objective. The used models are as shown in Figure 15. In there, one model was with an ordinary flat concrete slab of 125mm thick and other models were with the new roof slab insulation system with and without 50mm vegetation on top of the slab. The details of the new roof slab insulation system are as shown in Figure 16.

Figure 15, Physical models constructed for thermal performance comparison

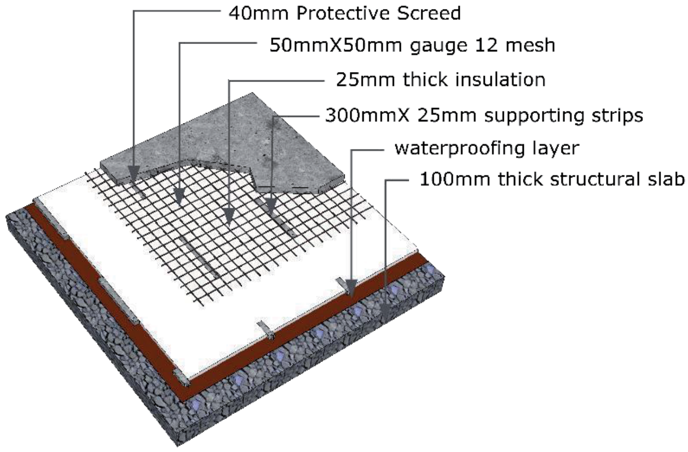

Figure 16, Newly designed roof slab insulation system (Kasun Nandapala & Halwatura, 2016)

Uninterrupted set of temperature readings were taken during continuous five days at ten-minute intervals until a constant ambient temperature was obtained using GL820 Midi Data Logger. The average temperature of each hour was calculated removing outliers and adjusted temperature readings of slab top and slab soffit were used in the comparison.

3.2. RESULTS

The experiment was conducted over a period of 24 hours during continuous five separate days. One graph representing whole five-day results was prepared considering the temperature values with minimum standard deviations. Figure 3 shows the graphical representation of slab soffit and slab top temperature readings of the model with an ordinary flat concrete roof over a time period of 24 hours, Figure 4 shows the graphical representation of slab soffit and slab top temperature readings of the model with the newly designed roof slab insulation system over a time period of 24 hours. In there, as shown in Figure 16, 25mm thick Expanded Polystyrene (EPS) layer with the thermal conductivity of 32 mW/mK was used as the thermal insulation barrier. Figure 5 shows the variation of slab top and soffit temperature readings of the new roof slab insulation system when there is a 50mm vegetation layer contained with an ordinary grass layer with a height about 60mm.

All the results were taken in 2nd week of September 2018 in Sri Lanka under tropical climatic conditions.

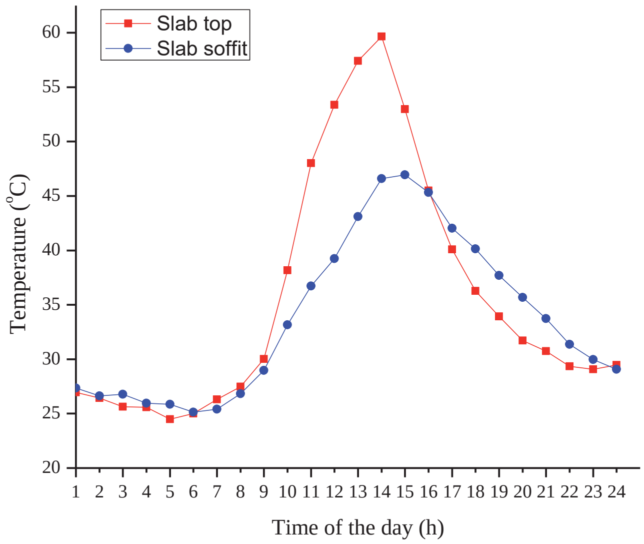

Figure 17, Slab top and slab soffit temperature readings of the model with an ordinary flat concrete roof over a period of 24 hours

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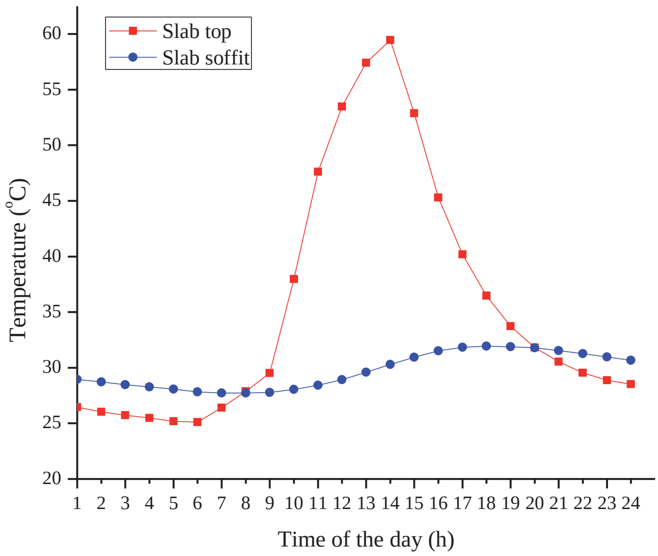

Figure 18, Slab top and slab soffit temperature readings of the model with new roof slab insulation system over a period of 24 hours

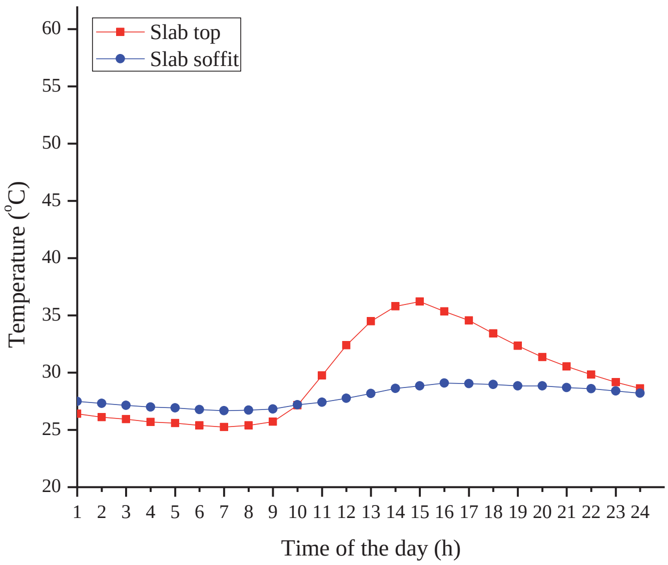

Figure 19, Slab top and slab soffit temperature readings of the model with a vegetated roof slab insulation system over a period of 24 hours

Self-insulation characteristics of the flat concrete roof due to the effect of thermal mass can be seen through Figure 17. However, in the case of the ordinary flat concrete roof, the slab soffit temperature has reached 45.5 °C which can be considered as a higher value which definitely results in thermal discomfort. When the novel slab insulation system was treated with a 50mm thick vegetation layer, the slab top temperature values show an outstanding reduction.

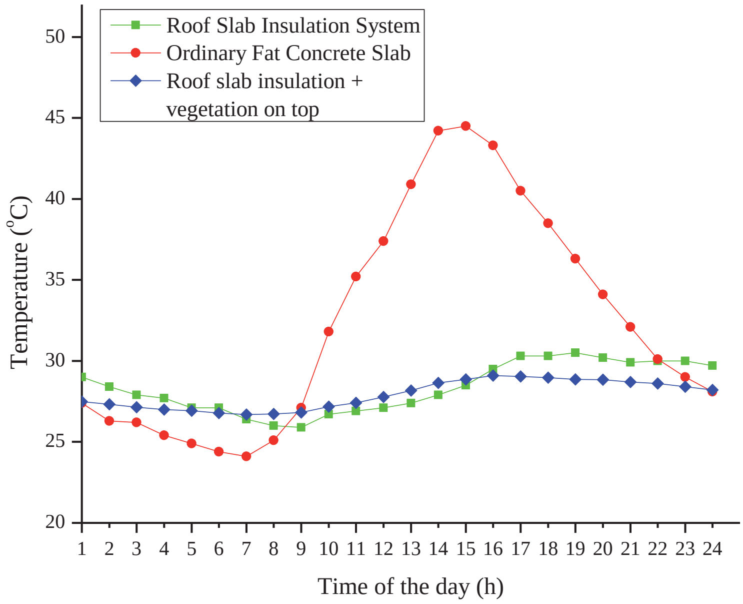

Figure 20, Slab soffit temperature readings of the considered three models over a period of 24 hours

Figure 20 clearly elaborates that the maximum slab soffit temperature at the presence of new roof slab insulation system has limited to 30.5 °C which can be considered as a satisfactory value. That value shows a further reduction to 29.1 °C at the presence of 50mm thick vegetation layer.

At the presence of the new roof slab insulation system, the slab soffit temperature lies between 25.9 °C and 30.5 °C. It is a very satisfactory condition comparing with the situation of the ordinary flat concrete roof. Since the temperature further goes down when it comes to the human occupation height, utilization as well as the capacity of air conditioners can be effectively mitigated. Anyhow, the vegetation layer has limited the slab soffit temperature in between 27 °C and 29.1 °C. But it is a slight difference from the performance of novel slab without vegetation and will be clearly discussed with respect to cooling load reduction under section 4.

It has been proven in a previously done study by one of the authors that, this kind of systems are having a heat gain reduction about 75% (Halwatura & Jayasinghe, 2008). According to the above results and since the new system was developed considering drawbacks of existing slab insulation systems, it can be predicted that the new roof slab insulation system is having a heat gain reduction more than 75%.

4. Peak cooling load reduction of the system

4.1. METHODOLOGY ADAPTED

A computer simulation was performed using the software package "Design Builder V5" to find out the cooling load reduction of a selected office building. A typical 15m x 15m office building was used since previous literature is available for such a building. Other housing elements ware included with less influence since the main objective was to study the heat gain effect through the roof. In there, external walls were selected to be 225mm thick ordinary brick walls, no windows were placed in East and West walls, and windows in North and South directions were shaded with 1m overhangs by means of preventing direct solar radiation penetration. The model used in the simulation is as shown in Figure 21.

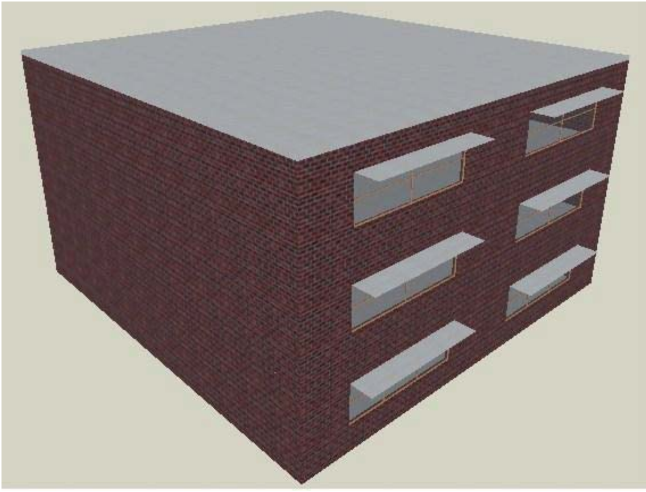

Figure 21, Virtual model used in computer simulation

4.1. RESULTS

Figure 21 office building shown in Figure 21 was analyzed in "Design Builder V5" to figure out the cooling load requirement to obtain neutral human comfort conditions on a typical summer day. Here, neutrality temperature was used as 26°C which has been mentioned as a reasonable value for tropical conditions (Jayasinghe, Attalage, & Jayawardena, 2002).

Table 7, Cooling load demand over a period of 24 hours

	Cooling required (kW)		
Time of the day (h)	**Uninsulated slab**	**Roof slab insulation system**	**Roof slab insulation system +50mm vegetation on top**
1	51.0030	55.2007	56.153
2	50.5711	55.0891	56.2200
3	48.4080	52.9293	54.1391
4	46.0967	50.6569	51.9040
5	44.2352	48.8192	50.0772
6	42.4248	46.9857	48.2246
7	41.4340	45.8303	47.0408
8	40.2569	43.3924	44.5793
9	52.1464	52.4538	53.4592
10	53.4525	49.2790	50.1252
11	59.9516	51.1731	51.6680
12	66.0990	53.1785	53.2508
13	70.0835	57.4962	54.5302
14	75.7483	60.7652	56.7003
15	81.1211	60.7652	59.6103
16	**83.8256**	64.0852	62.7123
17	83.6048	67.1330	65.7241
18	74.0339	62.0511	60.7000
19	73.0867	**67.3199**	**66.3531**
20	68.8214	66.1350	65.5401
21	65.9136	64.0991	63.8983
22	61.6634	61.5979	61.7556
23	56.9902	58.7270	59.1940
24	52.4503	55.6461	56.3776

The cooling energy requirement of aforesaid building at the presence of thermally insulated slabs and thermally uninsulated slab are as listed in
Table 7. The cooling load reduction calculation is as mentioned below;

Cooling load reduction with respect to novel slab system without vegetation and ordinary uninsulated roof slab

Cooling load reduction = [1- (67.3199/83.8256)] x 100% = 19.69% ≈ 20%

Cooling load reduction with respect to novel slab system with vegetation and ordinary uninsulated roof slab

Cooling load reduction = [1- (66.3531/83.8256)] x 100% = 20.84% ≈ 21%

Calculations show a 20% cooling load reduction due to novel roof slab insulation system over ordinary flat concrete roof slabs. The value gets a positive advancement about 1% due to the vegetation layer. But such a vegetation requires additional investment as well as proper maintenance. Since the cooling load difference is about 1%, roof slab insulation system without any vegetation can be chosen as the most fruitful solution.

3. Conclusion

The newly designed roof slab insulation system can be used to fulfil both requirements; indoor thermal comfort of buildings and cyclonic resistance addressing the key drawbacks of ordinary flat concrete roofs.

Since the comparison with literature data deviated that novel system can achieve more than 75% heat gain reduction under tropical climatic conditions and it was proven through performance analysis that new system provides about 20% cooling load reduction on a typical summer day it can be concluded that newly designed roof slab insulation system is suitable for addressing existing indoor thermal comfort issues of countries under tropical climatic conditions in an energy efficient manner providing extra cyclonic resistance to the structure too. At the presence of new roof slab insulation system, requirement of air conditioning equipment will be reduced and expected human comfort condition can be fulfilled with low capacity air conditioning equipment.

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Madujith Sagara Chandra, Kasun Nandapala, K.A.B. Weerasinghe, R.U. Halwatura: Engineering Perception Towards Vaasthu Shastra, Special Attention on Alignment of Openings in A Dwelling. 9th International Conference on Sustainable Built Environment (ICSBE) 2018, Proceedings of the special session on South Asia Sustainable cities by Bio-diversity ANDECO System Services, Kandy, Sri Lanka, 15/12/2018

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ENGINEERING PERCEPTION TOWARDS VAASTHU SHASTRA, SPECIAL ATTENTION ON ALIGNMENT OF OPENINGS IN A DWELLING

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Abstract: Although the contemporary era is full of the marvels of modern practices of building constructions, the shadows of customs and beliefs of building construction are still followed in various levels. These types of beliefs play a prominent role in residential and mini-commercial building construction and commonly visible in countries like Sri Lanka, India and China. In this study, one of the selected traditional belief in building construction, "Not having three or more aligned openings along the same row" was considered and the engineering perception of the belief was investigated by means of fluid dynamics simulations carried out with Autodesk Flow Design, Computational Fluid Dynamics (CFD) software. The results of the simulation conveyed that, the wind entered the house in one end, moved through aligned openings as a rapid flow making the air distribution to other parts of house less than 15% of total flow, but when the openings were not aligned (staggered openings) there was adequate air circulation to other spaces of the house. Finally, it was proven that the traditional belief, "Not having three or more aligned openings along the same row" is technically rational and there is an engineering significance of it. Hence, the considered belief is worth to be used in real-world applications.

Keywords: Residential Buildings; Three or More Aligned Openings; Customs and Beliefs; Computational Fluid Dynamics; Vaasthu Shastra; Feng-Shui

1. Introduction

Not only human beings but also all living beings from the tiniest insect which hardly can be seen with the naked eye to the gargantuan creatures use safer places to live, being protected from adverse climate changes and enemy attacks. With the passage of time, the power of thinking of human beings gradually increased and that power of thinking made them superior to every other being and the master of all other beings (Morris, 1996, 1999; Nehru, 1930). Eventually, people got nourished with knowledge and attitudes gained from nature and developed their sheltered places of living to well-prepared places much suitable for living. Eventually, these places were called houses which were the places always suitable for humans to live comfortably and places that ensured an excellent balance between people and nature which brought peace, happiness, health, wealth and prosperity to the inmates of the house (Patra, 2006).

The house which is the dwelling of human beings is the most important place of any family. It is not the place where people spend many hours of the day, for instances doctors spend more than half the day at hospitals, engineers spend weeks, months and years at their working sites and professors spend much time in the universities, but any of these places are not houses of any of previously mentioned professionals (Amarasooriya, n.d.; Patra, 2006). House is the place where people spend the most precious times of their lives with beloved family members. Because of that, people take much care when they build houses which are as sacred as shrines to the inmates of the house (Acharya, 1946; Silverman, 2007). People who make great efforts to make their dream home a better place much suitable for the ways and means of the family members have been using various types of knowledge resources such as Civil Engineering and Architectural knowledge and traditional customs and beliefs in building construction (Mak & Thomas Ng, 2005; Ranjeet.P, Narshima Rao.D.V.S., & Md. Akram Ullah Khan, 2016; Wattage Jeewa Bhanumathie, 1995). As a result of the development of science and technology, people commonly use Civil Engineering and Architectural concepts for construction activities. These concepts refer to the designation of space and creating and constructing the space needed for creating the day to day lives of people easy and the science of construction and designing the built environment (Koranteng, Afram, & Ayeke, 2015; Ulusoy & Kuyrukcu, 2012). Although the science and technology gloom in a high standard in contemporary time, the shadows of traditional customs and beliefs can be seen in most of the fields like building constructions, town and country planning, medicine etc. Likewise, people have not totally abandoned the customs and beliefs in building construction which consist of different branches like ancient Architecture, Astronomy, Vaasthu Shastra and Feng-Shui (Guptha, 2015; Mak & Thomas Ng, 2005; Ranjeet.P et al., 2016; Wattage Jeewa Bhanumathie, 1995). These beliefs in building construction which initiated from experiences obtained through daily activities of ancestors, highly affected the lives of the people and spread through the society. They were lasting for years, remain with slight changes proving that they have mixed with society (Fernando W.L.R., 1998; Gamage M.M., 2015). Almost all the customs and beliefs in building construction have been influenced by and based on Vaasthu Shastra, Feng-Shui and religious considerations of the society (Koranteng et al., 2015; Ranjeet.P et al., 2016). vaasthu shastra which belongs the period 1500-1000 BC is an ancient Indian knowledge as well as a science of Architecture, planning and designing (Patra, 2006). The word Vaasthu originally derived from the keyword “vas”, the meaning of dwell or dwelling place. Likewise, the term Vaasthu conveys a place of human dwelling more than a single household life (Amarasooriya, 2001; Arya, 2000; Patra, 2009). Feng-Shui is an ancient Chinese wisdom literally means “wind and water”, influences the layout and the design of cities and buildings (Huang, 2012; Koranteng et al., 2015). The concept of Feng-Shui born in China spread in western countries and it can be seen all around the world now (Mak & Thomas Ng, 2005). Though some beliefs lasted for years, some have been labelled as superstitions and have been rejected by the society (Weerasinghe K.A.B., Janaka K.G., & Galappaththi M.P., 2011). The superstitious influence in these beliefs can be part of cosmology and myths such as para-religious and religious practices of beliefs embraced by people and they are scared of those things thinking that not obeying and not practising them will bring terrible results ending in death (Chakrabarti, 1998; Glazer, 1978; Ofori, Tod, & Lavallee, 2016; Rudski, 2003). A number of customs and beliefs can be found in the building construction field and they are mainly used in small-scale building construction like houses rather than in large-scale construction like multi-storey buildings. (Koralage Dayarathna, 2010; Ranawaka Leelananda A.R., 2015; Weerasinghe K.A.B. et al., 2011). The most important thing is not “what other people believed” but “what are the meanings and backgrounds of the beliefs and how they can be used in the real world”. Some people get both money and time wasted by being slaves of those beliefs, being slaves of any belief get scared by their occult nature should not be done. The most ideal thing is understanding the rationality of those beliefs and using them in practical situations.

Although a number of Architectural and Sociological studies have been carried out regarding the customs and beliefs in building construction (Glazer, 1978), hardly any Engineering studies have been done. This study investigates the impacts of three or more aligned openings along the same row, in terms of Engineering technology based on CFD simulations.

2. Objectives

The primary goal of this study is to explore the engineering significance of not having three or more openings along the same row. The specific objectives of this study are as listed below;

I. To find the reasons for not having three or more aligned openings in dwellings

II. To obtain the popularity and the reasons for admitting the selected belief among the main stakeholders of building construction

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III. To access the impacts on indoor air circulation due to the alignments of three or more openings along a row

3. Methodology

I. A literature review was carried out to figure out the reasons for not having three or more aligned openings in dwellings

II. A questionnaire survey was carried out to investigate the contemporary status of the belief among stakeholders of building construction

III. CFD simulation by Autodesk Flow Design software was used to analyse the impact on indoor air circulation due to the alignment of openings, as shown in figure 1

4. Results

4.1. Results of the Literature Review

According to the literature available, the most important reasons for not having three or more aligned openings in houses were sorted out. They are as listed below;

- Disturbs the indoor air circulation of the house
- Reduces the strength of the main wall
- Violates the privacy of the inmates of the house
- Brings economic loss to the family
- Brings adverse repercussions to the family members

Among the above reasons, the first two have a direct Engineering influence while third depends on general understanding and day to day life experiences. The last two have been influenced by traditional customs beliefs. The very first reason was selected for further analysis by means of a questionnaire survey.

4.2. Results of the Questionnaire Survey

Results were extracted from the collected results of the questionnaire, based on the sample of 210 individuals containing 75 Civil Engineers, 45 Architects, 30 Astrologers (Vaasthu experts), 30 Carpenters and 30 Masons. View of non-aligned and aligned openings are as shown in figure 1

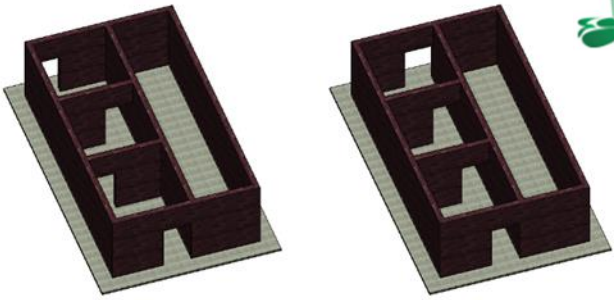

Figure 1: View of non-aligned openings and aligned openings

Results depended on the answers which were given by selected five categories of stakeholders. Some have selected more than one reason for not having three or more aligned openings. Each and every response was counted. The final results of the questionnaire survey are as illustrated in figure 2.

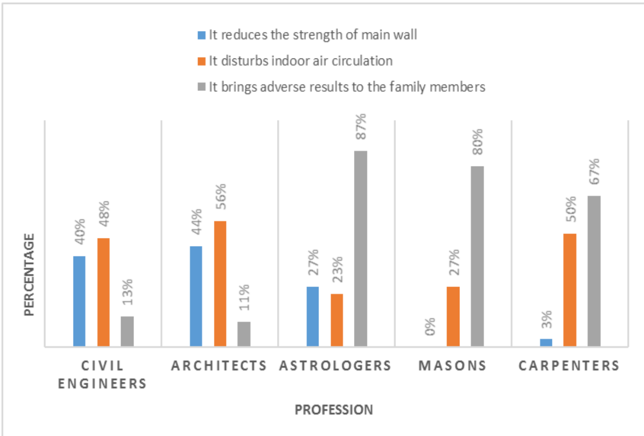

Figure 2: Reasons for accepting not having three or more aligned openings

With respect to total respondents 81% have opted not having three or more aligned openings in dwellings. Civil engineers and architects who have a proper theoretical knowledge and practical experiences of building construction, astrologers who are rich with Vaasthu and Feng-Shui concepts and masons and carpenters who do not have a proper educational status but have the practice of building structures, see the reasons for not having three or more aligned openings from different angles based on their own insight. Civil Engineers and Architects have looked at the scenario with respect to the engineering aspects, but Astrologers, Masons and Carpenters have used traditional beliefs which have been nourished with Vaasthu and Feng-Shui concepts.

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The responses of the stakeholders of building construction clearly show that only the majority civil engineers and architects correspond with the beliefs of building construction compatible with rational Engineering explanations. The main reason for not having three or more openings, the violation of indoor air circulation, opted by majority of Civil Engineers and Architects was selected for further analysis by means of Engineering Technology.

4.3. Results of the CFD Simulation

The ventilation effects inside the house due to the aligned and non-aligned openings were analyzed with fluid dynamics simulation. For that, 3D models were analyzed using Autodesk Flow Design software, based on the Navier-Stokes equation (equations have been mentioned in Appendix I). The analysis was done with respect to four wind speeds of 1m/s, 4m/s, 6m/s and 14m/s. the selected wind speeds were in between the minimum and maximum wind speeds which affect Sri Lanka ('Colombo, Sri Lanka 14-day weather forecast', 'Wind Colombo - Wind speed Sri Lanka - Weather Online', 'World Weather - Local Weather Forecast'). Four different arrangements of models were analyzed with respect to four different wind speeds. The arrangements of the models were models with 3m, 4m and the 7m gap between every two openings and a model with four openings with a 4m gap between each two openings with different opening arrangements.

The speeds of the flow lines are illustrated with separate colours in flow design software. For the study, 1m/s, 4m/s, 6m/s and 14m/s wind speeds conditions were considered, for an instance, only two extreme figures of 1m/s and 14m/s wind speeds have been inserted. Views of indoor air circulation when the gap among the openings are 3m with respect to the wind speeds of 1m/s and 14m/s are shown in figure 3 and figure 4.

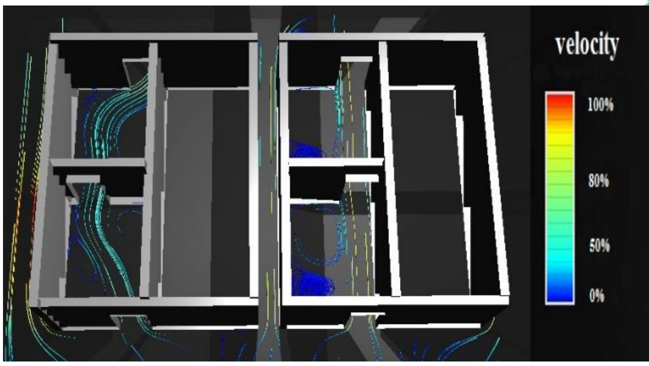

Figure 3. Indoor air circulation due to 1m/s wind speed

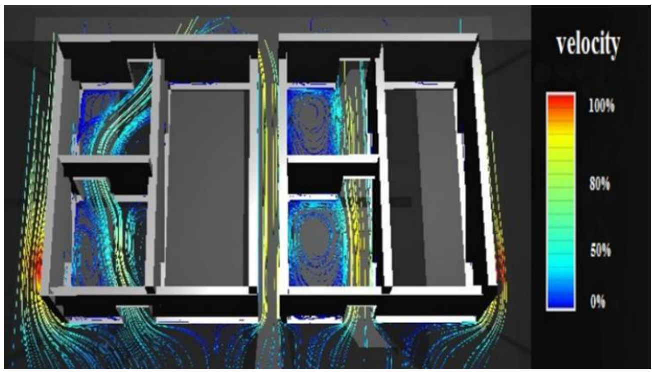

Figure 4: Indoor air circulation due to 14m/s wind speed

- When the openings are aligned in a row, flow lines rush through the openings with a high speed and flow lines with considerable wind speed hardly circulate through other spaces of the house. Therefore, those places become less ventilated
- When the openings are not aligned, flow lines get obstructed with the walls in between and circulate with turbidity. It allows the circulation of flow lines with more than about 50% of original wind speed to other spaces of the house. In this case, flow lines circulate through other spaces of the house as well as through the openings and keep the whole house properly ventilated
- When wind speeds approach high values, some amount of flow lines circulate through other spaces even when the openings are aligned, but it is not a situation which can be compared with air circulation when the openings are not aligned

- When there are more than four openings, the results get clearly verified. Flow lines with considerable speed can be seen in every part of the models when the openings are not aligned. But when the openings are aligned, even the few flow lines which can be seen in the spaces of the house contain zero speeds. Flow lines of 4m/s affecting a model with four openings are shown in figure 5

Figure 5. Indoor air circulation due to 14m/s wind speed

5. Conclusion

The study was done to explore the Engineering significance of not having three or more aligned openings in a dwelling with respect to the indoor air circulation. Questionnaire results obtained with respect to set of 210 stakeholders of house construction confirmed that 81% are obeying not having three or more aligned openings. In there two rational reasons for the selection was emerged; they were disturbing the indoor air circulation and reducing the strength of the main wall.

When there are three or more aligned openings along a row, the wind enters the house from one end of the house, blows through the openings with high speed as a rapid flow without any interruption. Because of that, the distribution of air flow to other spaces of the house become improper and whole house becomes insufficient in terms of ventilation. Numerically, the air distribution to other spaces become less than 15%. But when the openings are staggered, the wind entering the house from one end blows with many interruptions and it provides proper air circulation to every space inside the house. The technically rational conclusion of the Computational Fluid Dynamics (CFD) analysis is that having three or more aligned openings along the same row disturbs the proper air circulation inside the house and creates ventilation issues by not exposing the spaces inside the house to the fresh air flows.

Therefore, it is better to avoid having three or more aligned openings when placing openings inside a house. Further research must be done in order to investigate any structural effects, temperature variation within the buildings during daytime and night etc. to conclude whether this belief has a high impact in building construction. With respect to the simulations done in this study, the engineering significance of not having three or more aligned openings along the same row with respect to the indoor air circulation was clearly proved. This traditional belief contains an engineering significance and is worth to comply with and is ideal to be used in building construction.

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Appendix I

- Navier-Stokes equation

$$\frac{\partial u}{\partial t} = -(u \cdot \nabla)u + \nabla \cdot (\upsilon \nabla u) - \frac{1}{\rho}\nabla \rho + f$$

Where, υ = kinematic viscosity (constant), ρ = density (constant), f = external force (such as gravity)

X-component

$$\rho\left(\frac{\partial u}{\partial t} + u\frac{\partial u}{\partial x} + \upsilon\frac{\partial u}{\partial y} + w\frac{\partial u}{\partial z}\right) = -\frac{\partial p}{\partial x} + \mu\left(\frac{\partial^2 u}{\partial x^2} + \frac{\partial^2 u}{\partial y^2} + \frac{\partial^2 u}{\partial z^2}\right) + \rho g_x$$

Y-component

$$\rho\left(\frac{\partial \upsilon}{\partial t} + u\frac{\partial \upsilon}{\partial x} + \upsilon\frac{\partial \upsilon}{\partial y} + w\frac{\partial \upsilon}{\partial z}\right) = -\frac{\partial p}{\partial y} + \mu\left(\frac{\partial^2 \upsilon}{\partial x^2} + \frac{\partial^2 \upsilon}{\partial y^2} + \frac{\partial^2 \upsilon}{\partial z^2}\right) + \rho g_y$$

Z-component

$$\rho\left(\frac{\partial w}{\partial t} + u\frac{\partial w}{\partial x} + \upsilon\frac{\partial w}{\partial y} + w\frac{\partial w}{\partial z}\right) = -\frac{\partial p}{\partial y} + \mu\left(\frac{\partial^2 w}{\partial x^2} + \frac{\partial^2 w}{\partial y^2} + \frac{\partial^2 w}{\partial z^2}\right) + \rho g_z$$

Radial component

$$r: \rho\left(\frac{\partial u_r}{\partial t} + u_r\frac{\partial u_r}{\partial r} + \frac{u_\phi}{r}\frac{\partial u_r}{\partial \phi} + u_z\frac{\partial u_r}{\partial z} - \frac{u_\phi^2}{r}\right) = -\frac{\partial p}{\partial r} + \mu\begin{bmatrix}\frac{1}{r}\frac{\partial}{\partial r}\left(r\frac{\partial u_r}{\partial r}\right) + \frac{1}{r^2}\frac{\partial^2 u_r}{\partial \phi^2} + \frac{\partial^2 u_r}{\partial z^2} - \frac{u_r}{r^2} \\ -\frac{2}{r^2}\frac{\partial u_\phi}{\partial \phi}\end{bmatrix} + \rho g_r$$

Tangential component

$$\phi: \rho\left(\frac{\partial u_\phi}{\partial t} + u_r\frac{\partial u_\phi}{\partial r} + \frac{u_\phi}{r}\frac{\partial u_\phi}{\partial \phi} + u_z\frac{\partial u_\phi}{\partial z} - \frac{u_r u_\phi}{r}\right) = -\frac{1}{r}\frac{\partial p}{\partial \phi} + \mu\begin{bmatrix}\frac{1}{r}\frac{\partial}{\partial r}\left(r\frac{\partial u_\phi}{\partial r}\right) + \frac{1}{r^2}\frac{\partial^2 u_\phi}{\partial \phi^2} \\ + \frac{\partial^2 u_\phi}{\partial \phi^2} + \frac{2}{r^2}\frac{\partial u_r}{\partial \phi} - \frac{u_\phi}{r^2}\end{bmatrix} + \rho g_\phi$$

Axial component

$$z: \rho\left(\frac{\partial u_z}{\partial t} + u_r\frac{\partial u_z}{\partial r} + \frac{u_\phi}{r}\frac{\partial z}{\partial \phi} + u_z\frac{\partial u_z}{\partial z}\right) = -\frac{\partial p}{\partial z} + \mu\left[\frac{1}{r}\frac{\partial}{\partial r}\left(r\frac{\partial u_z}{\partial r}\right) + \frac{1}{r^2}\frac{\partial^2 u_z}{\partial \phi^2} + \frac{\partial^2 u_z}{\partial z^2}\right] + \rho g_z$$

2.4.1(3)

F.R. Arooz, Madujith Sagara Chandra, Kasun Nandapala, R.U. Halwatura: Defining the Effective Size and Proportions of a Mud-Concrete Block. Emerging Technologies for Industrial Sustenance, at University of Vocational Technology, Sri Lanka, January 2018;

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Emerging Technologies for Industrial Sustenance

DEFINING THE EFFECTIVE SIZE AND PROPORTIONS OF A MUD-CONCRETE BLOCK

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ABSTRACT

This paper presents how to define the effective size and proportion for a novel, self-compacting masonry walling material named Mud-Concrete, which is developed to achieve the sustainable goals in the construction industry. Whilst thinking of sustainable approaches of introducing the product to market, the block sizes, proportions should be rationalized and socially acceptable. Thus, qualitative methods were adopted to analyze the social acceptance of selecting the effective sizes and proportions of Mud-Concrete block considering the golden proportions. Results defined that 225mm x 100mm x 200mm is the most preferable Mud-Concrete block type, because people are more familiar with the proportions which are already existing.

Keywords: Block sizes, proportions, golden proportions, Sustainable, Mud-Concrete Block (MCB)

1. INTRODUCTION

Aesthetics treats the natures and conditions of occurrence of various human experiences such as the experiences of the beautiful, the garish, and the cute, while the philosophy of art in contrast treats the nature of works of art (Eldridge, 1985). Aesthetic concepts in design are always linked with the visual aspects, though it is structurally viable or not. Indeed, the appearance may be an essential part of purpose or use.'Engineering' and 'Aesthetics' are not isolated disciplines, having as they do links with many other disciplines as well (Kulasuriya et al., 2002). Thus, the form making and maintaining the correct proportions with shapes are one of the main core concepts of aesthetics. While form often includes a sense of three-dimensional mass or volume; shape refers more specially to the essential aspects of form that governs its appearance. Size is the characteristic outline or surface configuration of particular forms and it is the key aspect of identifying and categorizing different forms. The Fibonacci numbers and golden proportions (length/width=1.6) gave a great lead to this research when analyzing the relationship between form, shape and size, (Han et al., 2012), (Vogel, 1979), (Fiorenza and Vincenzi, 2013). The Sequence has been described as the "magical intersection" between the fields of mathematics and beauty, and that is exactly what it is. Fibonacci proved that everything has a reason for its formation or the existence in nature and helped people understand why things are the way they are (Han et al., 2012), (Fiorenza and Vincenzi, 2013). With this thought, a literature survey was done to explore whether the conventional soil-based masonry blocks (fired and unfired) can be introduced to the market with these concepts.

Bricks and blocks are produced in many formats as solid, perforated and hollow. Bricks are typically 215mm x102mm x65 mm (length x width x height). Whilst conventional sized blocks are available in lengths 400mm x 600mm, heights 150mm x 300mm and a wide range of thicknesses between 60 mm to 250 mm (Hendry, 2001). According to the SLS standards, the minimum required wall thickness, handling considerations (weight) and method of compaction governed the block dimension of Compressed Stabilized Earth Blocks (CSEB) (Sri Lankan Standard Institute, 2009).

Table 1: Work Sizes of CSEB Blocks

Block Type	Length (mm)	Width (mm)	Height (mm)	Block Description
I	230	110	75	Plain block
II	240	115	90	Solid or hollow block
III	290	140	90	plain or interlocking block
IV	220	140	130	plain or interlocking block
V	220	220	130	plain or interlocking block

(Source: Sri Lankan Standard Institute, 2009)

Table 1 shows the different work sizes of CSEB blocks. According to the face dimensions and width of the block the purchaser can specify the work size of the required CSEB block during a construction.

This paper focuses on a novel walling material called Mud-Concrete which is produced using soil, cement and water (Arooz and Halwatura, 2017, Halwatura, 2016, Arooz et al., 2017). It is a self-compacting material which is capable of self-consolidating without any external efforts like vibration or poking. With this quality Mud-Concrete can be formed in any shape and size using an appropriate formwork. But achieving the sustainable demands while maintaining the public preference needs a lot more attention when introducing a block masonry to the market. As to initiate the whole composition visually attractive the golden ratio was integrated into each block type. Thus, the main objective of this study is to identify the effective block size and proportion of a proposed Mud-Concrete Block. As a result, the following methodology was adopted.

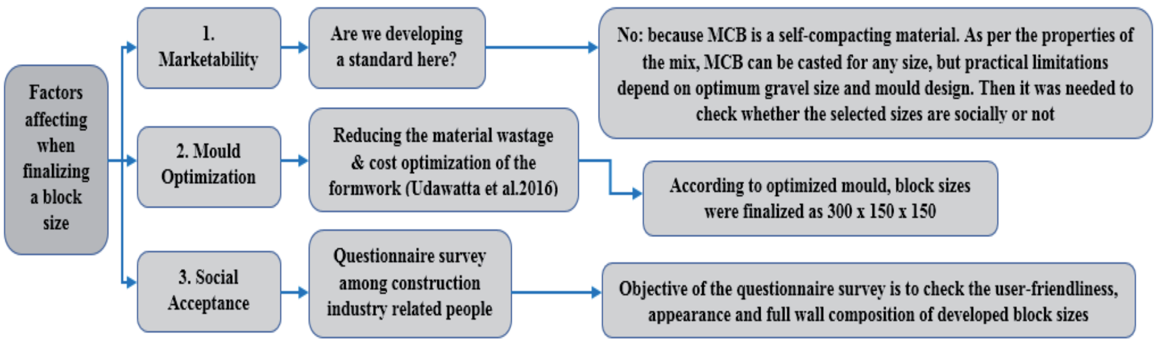
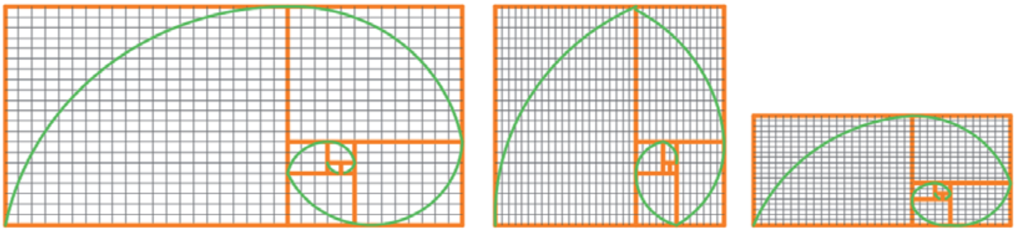


Figure 1: Factors Affecting the Finalizing of a Size of a Masonry Block

2. METHODOLOGY

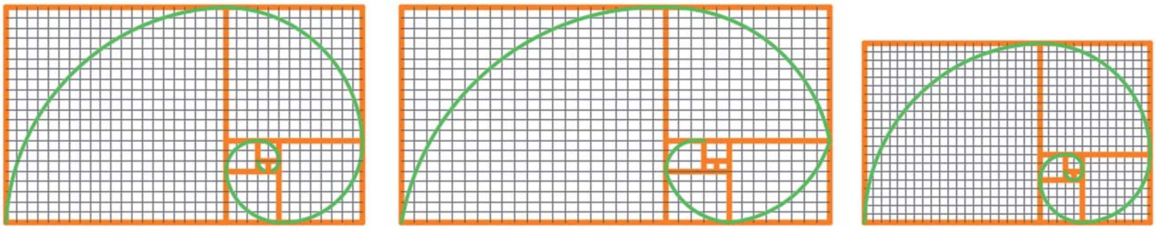
In this methodology, the first section was analyzed through a literature survey. Thus, a question was raised as "what the exact factors are affecting the defining of the size of a masonry block when introducing it to the general public?" Figure 1 shows that three (03) factors mainly affect the finalizing of a block size such as, marketability, mould optimization and social acceptance on defining the effective sizes and proportions of the block. Developing a standard block size mainly affects the factor of marketability. However, Mud-Concrete being a self-compacting material, theoretically it can be formed in any size while catering to the optimum gravel size of the mix design. Because gravel governs the strength of Mud-Concrete mix. According to mix design of the Mud-Concrete the optimum gravel size is 4.75mm -20mm in 35% of the total weight of the dry mix (Arooz and Halwatura, 2017). Therefore, the selected block size should be capable to keep enough gravel, sand and fine with its porous structure while achieving its minimum 2.8 N/mm^2 (dry strength) with 4% cement from the dry mix. Subsequently, there was a need to check whether the selected block sizes are socially acceptable or not. Thus, a questionnaire survey was conducted among a selected sample of 260 people who were related to the construction industry (Ex: Architects, Engineers, Quantity surveyors and construction workers). The two (02) attributes were considered in developing the physical proportions of a Mud-Concrete block as follows: 1] Appearance (Bonded block pattern of a wall) and 2] Size (Length, width, height and the weight of an individual block).

These two attributes were directly used to prepare the questionnaire and analyze the findings of the study.



(A) Height/Width = 2 (not in the golden ratio) (B) Height/Width = 1 (not in the golden ratio) (C) Height/Width = 2.25 (not in the golden ratio)

Figure 2: Height to Width Ratio of Block Type "A", "B" and "C" (source: author)



(D) Height/Width = 1.6 (in the golden ratio) (E) Height/Width = 2 (not in the golden ratio) (F) Height/Width = 1.6 (in the golden ratio)

Figure 3: Height to Width Ratio of Block Type "D","E" and “F" (source: author)

Table 2: Details of Used Mud-Concrete Block Types for Questionnaire Survey

Block Type	(Length x Height x Depth)	Reasons for size selection
A	400 x 200 x 200	Similar proportions to standard concrete blocks
B	200 x 200 x 200	Square shape block
C	225 x 100 x 200	Similar proportions to standard engineering bricks
		(Though the standard brick size is 215 x 65 x 102.5 mm
		225 x 100 x 200 mm was used depending on the
		Maximum aggregate size of the MCB mixture
D	250 x 150 x 200	1.6 - Follows the golden ratio (large size)
E	300 x 150 x 200	Sizes according to the optimized mould (Udawatta et al., 2016)
F	200 x 125 x 200	1.6 – Follows the golden ratio (Small size)

Though there was a size (300x150x150) mm finalized through the study based on mould optimization, it was interesting to know whether these sizes are acceptable in the public eye who were willing to use these technologies. Therefore, the first step of the research was commenced through casting different types of MCB as shown in Table 2. A few blocks from each type were kept presenting the size (Length, width, height and the weight of an individual block) of the block to the selected respondents. After that 3’-0”x 4’0” walls were constructed from each block type. Stretcher bond was used in every single wall construction. The selected respondents (sample) were asked to answer the given questionnaire and rate their preferences. The rating system was graded as 0 (rejected)= 1, 1(very poor) =2, 3(poor)= 3, 3(satisfactory)=4, 4(good)=5, 5(very good) =6.

3. RESULTS & DISCUSSION

In the investigation on defining the appearance, it was found that a considerable number of respondents preferred block type “C” and “E” (Figure 4). In addition, block type “A” also received a reasonable number of preferences where the results reached for satisfactory level. The second investigation was carried out to define the size of the Mud-Concrete block (Figure 5). Here it was found that the most preferred block types were “C”. Further, the block type “E” also reached to the satisfactory level. Despite the fact that the Fibonacci code and golden ration has given the great explanation in nature forms, respondents preferred the type “C” more, (225mm x 100mm x 200mm) which was similar to the proportions of the standard brick size. Then an argument could be made that people don’t want something truly new, they want the familiar things done differently. But the block type “E”, the size derived from formwork optimization was also acceptable and it also reached to the satisfactory level of the respondents. The block types “D” and “F”, which follows the 1:6 golden ratio have given the similar responses. The block type “B”, the square one is the least preferable form of MCB.

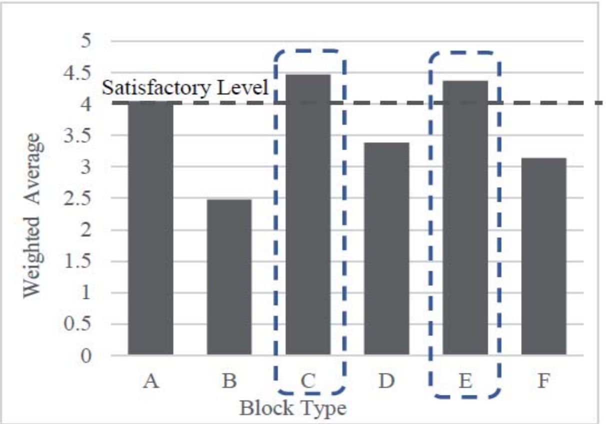


Figure 4: Average responses on different sizes of Mud-Concrete Blocks

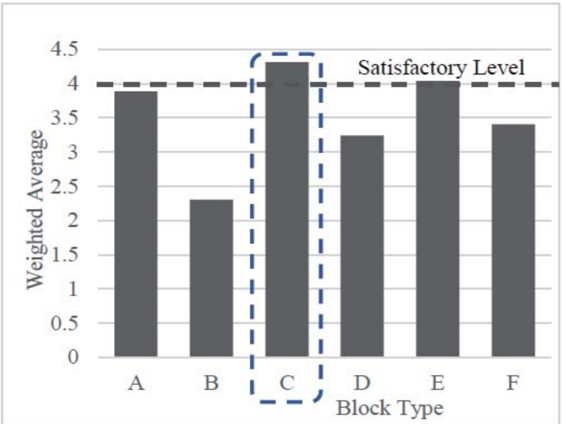


Figure 5: Average responses on different sizes of Mud-Concrete Blocks

4. CONCLUSIONS

Proper research needs to be conducted prior to introducing a novel material to the market in terms of thinking of the social acceptance towards the technology. Generally, people do love to select what is exactly familiar to their eyes when judging on the proportions. In addition, the choices could be varied according their very own personal experiences. As a final point, the study defines the 225mm x 100mm x 200mm (Block type “C”) as the most preferable Mud-Concrete block type. Further, 300mm x 150mm x 200mm (Block type “E”) is also acceptable and that can recommend to be utilized when thinking about the aspects of reducing the material wastage and cost optimization of the formwork.

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2.4.1(4)

K. Nandapala and R. U. Halwatura, “Developing a structurally sound and durable roof slab insulation system for tropical climates,” in Proceedings of the 8th International Conference of Faculty of Architecture Research Unit (FARU), University of Moratuwa, vol. 1, (Taj Samudra Hotel), pp. 201 – 214, Dec. 2015.

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DEVELOPING A STRUCTURALLY SOUND AND DURABLE ROOF SLAB INSULATION SYSTEM FOR TROPICAL CLIMATES

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Abstract

Flat roof slabs are gaining its popularity day by day due to its advantages like cyclonic resistance, possibility for future expansion and the possibility of using them as additional working space. However, the major issue associated with roof slabs is thermal discomfort, for which, active cooling in the forms of fans and air-conditioners is the most common remedy used. This has led to extensive use of energy, increasing the operational cost of the buildings and, in the macro scale, contributing to global warming as well. Hence, the current trend is to go for passive techniques. Insulating roof slabs is identified as a better passive way to address the stated issues. In this study, several existing roof slab insulation techniques were discussed and their benefits and drawbacks were identified. While ensuring the same thermal and structural capacity of the insulation system, a new system was developed to address the drawbacks of existing systems. Computer based modelling were used to optimize the system and the small scale model testing was used to validate the results obtained by the computer simulations. Finally, a new insulation system was developed with enhanced thermal performance, structural capacity and the durability.

Keywords: *Passive Cooling, Roof Slab Insulation, Structural performance, durability*

1. Introduction

Due to the rapid development taking place in the last couple of decades, 'land' has become one of the most expensive commodities in the world, particularly in urban areas. In this context, multi-storey construction has widespread throughout the world as it enables the users to have a larger working area in a small footprint. Further, use of flat concrete roof slabs has aggravated its popularity as it allows the flexibility to the users to use the space as either a working space or a roof top garden (Banting, 2005; Berardi, GhaffarianHoseini, & GhaffarianHoseini, 2014; Halwatura, 2013). In addition, robustness that a concrete roof slab incorporates to a building enhances the disaster resistance, particularly against cyclones (Halwatura, Mallawarachchi, & Jayasinghe, 2007).

Nevertheless, since concrete is a relatively high thermal conductor, it gets heated up in the daytime and emits long wave radiation to the space underneath, causing a severe thermal discomfort to the occupants in its topmost floor. It has been found that if this issue can be addressed, it will make flat concrete roof slabs more popular among the general public (Nandapala & Halwatura, 2014).

The most common remedy adapted to address this issue is, active means of cooling in the form of fans and air-conditioners. Even though that it solves the issue of thermal discomfort, it is at a higher cost in the form of higher usage of energy, leading us back to the biggest issue that the current world is facing, Global Warming.

It has been found out that in Singapore, buildings use up to 57% of the total energy usage of the country (Kwong, Adam, & Sahari, 2014), and In Malaysia, a country with a similar tropical climatic conditions, more than 30% of the total energy usage is for making buildings thermally comfortable (Dong, Lee, & Sapar, 2005). This proves that around 20% of the total energy used in tropics is for providing thermal comfort in buildings. It is obvious that this is beyond the world can afford, implying that the use of active cooling techniques is not an appropriate solution for thermal comfort in long run. Hence, passive cooling techniques have become popular in the world (Al-Obaidi, Ismail, & Abdul Rahman, 2014; Alvarado & Martínez, 2008; Sadineni, Madala, & Boehm, 2011), insulation in particular (Al-Homoud, 2005; Brito Filho & Santos, 2014; Dylewski & Adamczyk, 2014).

There are several roof insulation techniques tried out in the world, and their heat reduction potentials have been studied. Applying a cool paint is one such technique. In a research carried out in Florida, USA, it has been proven that up to 38% energy saving can be obtained by applying a cool paint (Parker & Barkaszi Jr., 1997). Another research in Italy, a reduction of 54% energy demand is observed (Romeo & Zinzi, 2013). In Greece a set of researchers has used a 60mm air gap as an insulator, and obtained a daily heat gain reduction of 56% (Dimoudi, Androutsopoulos, & Lykoudis, 2006). There is another technique used in Sri Lanka with a 25mm polyethylene layer as the insulator, proving a heat reduction of 75% can be obtained in a tropical climatic condition (Halwatura & Jayasinghe, 2008).

Above figures incontrovertibly suggest that insulation can be very effective in any climatic condition. Since this study focuses on tropics, the system developed in Sri Lanka is found to be the most recent and the best to suit the conditions. However, there are some drawbacks associated with this method. The issues associated and the proposed remedies are discussed in this paper.

2. Findings so far

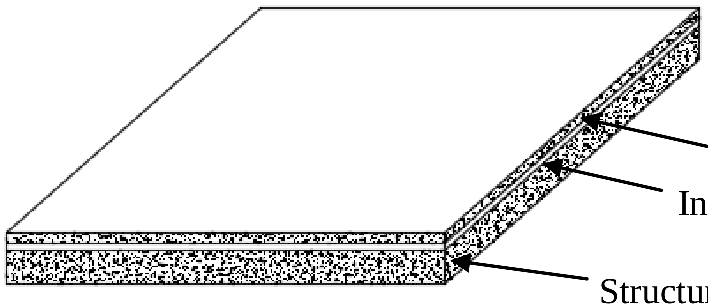

Figure 10: insulation system with a continuous insulation layer

As it has been mentioned, thermal discomfort is the dominant drawback associated with roof slabs, and for which insulation has been identified as a better remedy. The most common arrangement used in practice is shown in Figure 10.

This system is implemented and tested practically, and proven that this performs really well in thermal aspects. However, this imposes a restriction on loading since a layer of weak material is sandwiched in the system.

Figuring this out, a system has been developed with a set of continuous concrete strips within the insulation layer as shown in Figure 11 (Halwatura & Jayasinghe, 2008). This is proven to be structurally sound, with the capability of bearing any practical load acted on a roof.

However, leakages of slabs were observed in long run in the slabs constructed. After an investigation, water was found to be stagnant in the areas where insulation material is. This can be elaborated as follows;

The supporting arrangement of this system in the insulation layer (plan view) is shown in Figure 12. There’s no drainage path for a water drop which passes through the cracked screed to the insuation layer, as the insulation material is enclosed by a set of continuous concrete strips. The waterproofing layer that is used in slabs is not designed to withstand a water head, hence has failed.

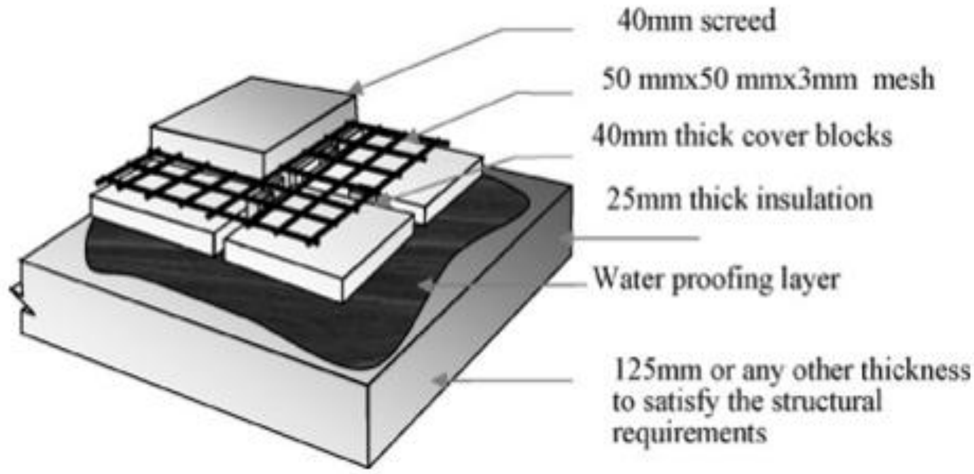

Figure 11: The system with continuous concrete strips (Halwatura & Jayasinghe, 2008)

Hereafter, this paper describes the conceptual design of a drainage path within this insulation system.

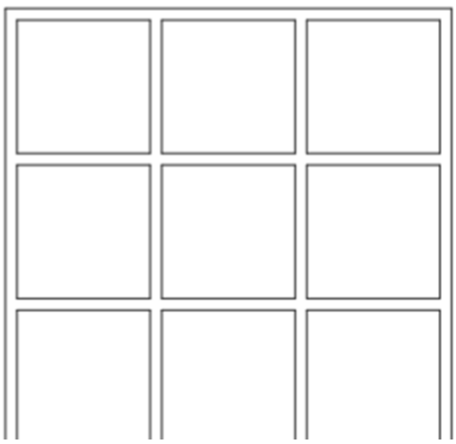

Figure 12: Supporting arrangement of screed within insulation layer in the system with continuous concrete strips (plan view)

3. Methodology

A literature survey has been carried out to figure out the requirement of such a technique in the local context. Further, the existing techniques that have been tried out throughout the world were studied, and the systems that is most efficient has been picked out for further improvement.

Then those particular systems is further investigated by means of a further literature review and a field study to identify the practical issues to be addressed.
In the study, it has been identified that structural performance and the durability are the main issues associated with those systems. The method that was adapted to address those is described throughout this paper.

4. The Conceptual Design

4.1 STEP 1: REMOVING STRIPS IN ONE DIRECTION

The first option considered was to remove strips in one direction as shown in Figure 13. The objective of designing the system, in first place, is to remove the restriction for loading. Hence, the system has to be designed in such a way that it can withstand any practical load applied on that. Therefore, a structural analysis was carried out assuming that the imposed load applied on that is 5kN/m^2, which is the maximum specified in BS6399-1:1996 (Code of Practice for Dead and Imposed Loads).

In this context, there were four variables to be considered.

1. Spacing between strips
2. Size of strips
3. Mix proportion of concrete used.
4. Reinforcement arrangement of the top screed.

An optimum spacing for the system was to be found out for the system. Because the system could have failed if the strips are too far apart of each other, and the effectiveness of the system reduces drastically if they are placed too closer by since the insulation material is replaced by concrete

.

Reducing the concrete area as much as possible is a major objective in this optimization process of the system. Hence, a minimum size that can bear the predicted load had to be found out.

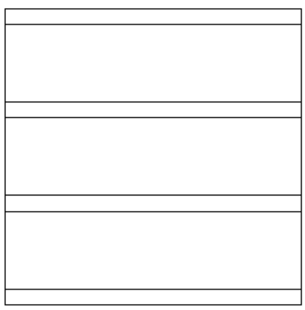

Figure 13: supporting arrangement after removing strips in one direction

The mix proportion to be used in the strips plays a major role as well. It has to be strong enough to carry the load, and should be able to be compacted in an area of a width of 40mm. Hence, a concrete with a lower maximum aggregate size (chip-concrete) was used. A suitable proportionating was necessary to be done.

The screed had to be designed as a slab itself as this system is to be used as a load bearing structure. Since concrete is a material which is very weak in tension, some arrangement of steel had to be incorporated into the system. Several options of having two reinforcement nets were considered. Bottom reinforcement was tried fixed to a 2” x 2” gauge 12 mesh due to the convenience of construction. There were four options considered for the top net: no reinforcement, a 6mm mild steel bar near supports, a 10mm tor steel bar near supports and a same type of a mesh (double nets), with an obvious preference for the ‘no top reinforcement’ case over others.

Since it was not practical to play with all the variables, size of strips was fixed to 50 mm and the concrete was assumed to have a strength of 15 N/mm^2 for initial evaluations. The results obtained by computer simulations by varying the spacing of the strips and type of reinforcement is shown in Figure 5. It suggests that the system can be implemented without any top reinforcement if the strips are provided in a spacing of less than 540 mm (

Figure 14). at this stage, the finalized values for the four variables stated above are as follows;

1. Spacing between strips – 540 mm
2. width of the strips - 50 mm
3. Strength of concrete used – 15 N/mm^2
4. Reinforcement arrangement of the top screed – a single net of 2” x 2” gauge 12 mesh

4.2 STEP 2: OPTIMIZING THE STRIP IN ITS LONGITUDINAL DIRECTION

As it has been stated, reducing the concrete area within the insulation layer is a prime objective of this study. Hence, several options were considered to select the optimum arrangement, varying the spacing of the strips (in transverse diration). In this case, there were three additional variables considered.

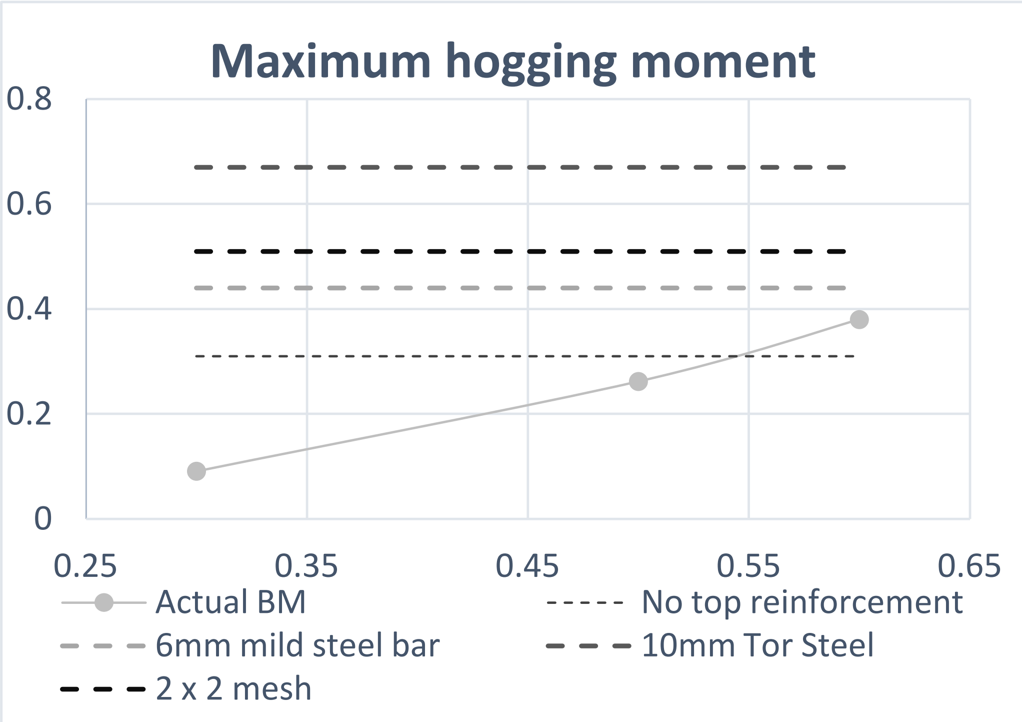

Figure 14: Bending moments and bending moment capacities for different reinforcing arrangements

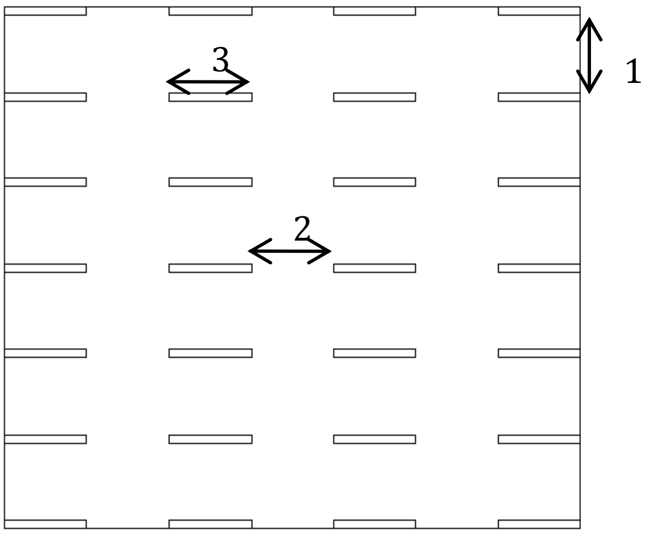

Figure 15: Variables to be considered in optimizing the strips in longitudinal direction

1. Transverse spacing of strips (number 1 in
2. Figure 15)
3. Longitudinal spacing between strips (number 2 in
4. Figure 15)

5. Length of the strips (number 3 in
6. Figure 15)

Sixty possible options were considered by varying these variables and three feasible options were picked out considering the structural aspects (Table 1).

Table 1: The short-listed systems with discontinuous concrete systems with supports

span in transvers direction(mm)	Length of the strip(mm)	Clear spacing between strips (mm)
300	300	400
400	300	300
500	200	100

4.3 STEP 3: FLAT SLAB ARRANGEMENT

The options considered so far were of a typical beam-column supporting system of a slab. However, it was worthwhile to consider the option of a flat slab arrangement too. The results obtained are shown in Figure 16 (only hogging bending moment is shown as it was the critical aspect considered). The results suggested that it is possible to implement this system if 50 mm blocks are spaced at 150 mm.

4.4 STEP 4: SELECTING A SUITABLE WIDTH OF THE STRIPS

The major objective of this study was to find out the optimum supporting arrangement to carry any possible load acting on it. Further, in section 3.1, only two out of four variables in total were considered in the design. In this step, the minimum width of the strip has been worked out.

Since the height of the supporting strips is short with respect to other length, the most likely way is to fail in compressive strength. Hence, the minimum width required is calculated by a simple compressive strength calculation. The results are as shown in Table 2.

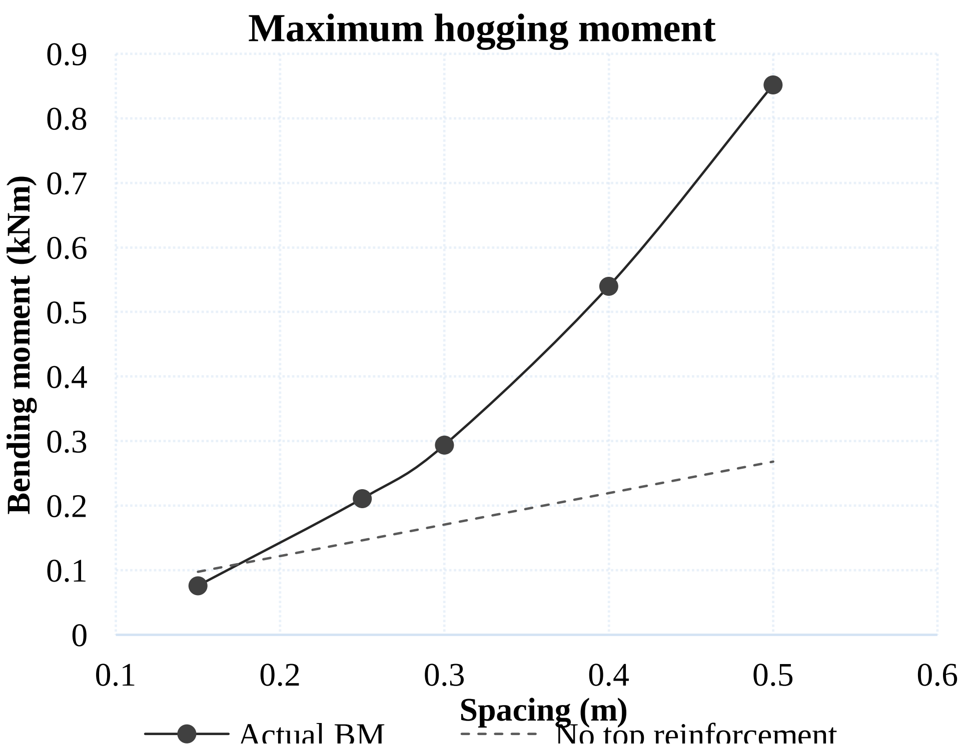

Figure 16: Bending moments and bending moment capacities of flat slab arrangements with different spans

It shows that a very small width is sufficient to carry the load. However, a minimum width of 25mm is selected considering the practical construction aspects.

Table 2: Calculations for finding minimum width of strips

	300mm in transverse	**400mm in transverse**	**500mm in transverse**	**Flat slab arrangement**
effective area (m^2)	0.21	0.24	0.15	0.04
Dead load (kN)	0.2076	0.2394	0.153	0.0399
live load (kN)	1.05	1.2	0.75	0.2
total load kN (with partial factors of safety)	1.97	2.26	1.41	0.38
minimum area (mm^2)	131.38	150.34	94.28	25.06
minimum width (mm)	0.44	0.50	0.47	5.01

4.5 STEP 5: SELECTING THE BEST SYSTEM

As the process suggests so far, the possible options for the structural arrangement is short-listed to four. The next step was to pick one out.

Since the objective is to minimize the concrete area within the insulation material as much as possible, the concrete area of approximately100 m^2- slab was considered. As Table 3 suggests, the flat slab arrangement has a significantly higher percentage than other options, which are more or less having a similar area of concrete. The second option has the lowest value and hence was selected for actual scale testing.

4.6 STEP 6: SELECTING A SUITABLE CONCRETE MIX

The other variable that was fixed in section 3.1 was the mix proportion of concrete used. Since the supporting strips are of 400 mm x 25 mm, it was necessary to specify a lower maximum aggregate size for concrete. As chipped metal with a maximum size of 10 mm is a common construction material a mix design was performed to achieve a strength of 15N/mm^2. Several options were considered as shown in Table 3.

Table 3: concrete areas of the four short-listed systems

	300mm in transverse	**400mm in transverse**	**500mm in transverse**	**Flat slab arrangement**
Concrete area (m^2)	3.71	3.51	3.57	5.61
Total Area (m^2)	97.5	105.5	101.5	99.0
Ratio	3.8%	3.3%	3.5%	5.7%

All the mixes tested did achieve the target strength of 15 N/mm^2. The next step was to specify a volume batch mix proportion to be used in the industry. From a simple calculation it has been found out that the mix with water-cement ration of 0.7 has roughly 1:2:3 proportion of cement, sand and metal respectively.

4.7 STEP 7: ACTUAL SCALE TESTING

Having finalized the system, the next step was to validate results by actual scale casting. The system was loaded with a proving ring calibrated to measure the load applied. The deflection with the applied load was measured by a dial gauge. Both readings were continuously taken till the system fails entirely. The results are shown in Figure 8.

The graph in figure 8 shows that the system can be loaded higher than 30kN without a serviceability failure. This is sufficient to carry any practical load on top of a roof.

5. CONCLUSIONS

Using flat slabs as roofs is a good strategy to recover the land, one of the scarcest resources in an urban environment. Further, it enhances the robustness of structures and thereby increases the resistance to natural disasters, of which the intensity and the severity increases day-by-day as a result of the climate change in the world. However, it increases thermal discomfort in the uppermost floor as the slab acts as a heated body and emits longwave radiation to the immediate space underneath. Mechanical cooling is the most common remedy used in the industry, but it increases the energy consumption which is not favourable for a sustainable world.

Table 48: Mix design options tested to obtain 15 N/mm^2 strength

W/C ratio	Cube #	Load (kN)	Size of the Block		Strength (N/mm2)	Average Strength (N/mm2)
			Length (mm)	Width (mm)		
0.78	1	517.8	150	153	22.56	22.48
	2	530.4	148	151	23.73	
	3	478.3	155	146	21.14	
0.75	1	506.3	150	151	22.35	23.78
	2	526.7	151	149	23.41	
	3	594.7	155	150	25.58	
0.70	1	478.8	150	153	20.86	23.97
	2	562.5	148	147	25.85	
	3	551.5	150	146	25.18	
0.65	1	536.4	150	150	23.84	25.40
	2	567.2	146	148	26.25	
	3	599.5	153	150	26.12	
0.60	1	683.4	150	153	29.78	27.63
	2	589.1	149	151	26.18	
	3	609.3	155	146	26.92	

In this context, insulation of slabs has gained the popularity among the researchers in the modern world. There are many such techniques developed in the world, of those the most effective method was selected. A field study was done to identify the performance of the system. It was noted that this system has a drainage issue as some instances the slabs have become leaked.

The system was further investigated to find out the reason, and a separate technique was developed with a minimum concrete area and a proper drainage path. It has been found out that 300 mm x 25 mm strips with 300 mm clear span, and a transverse spacing of 400 mm is structurally capable.

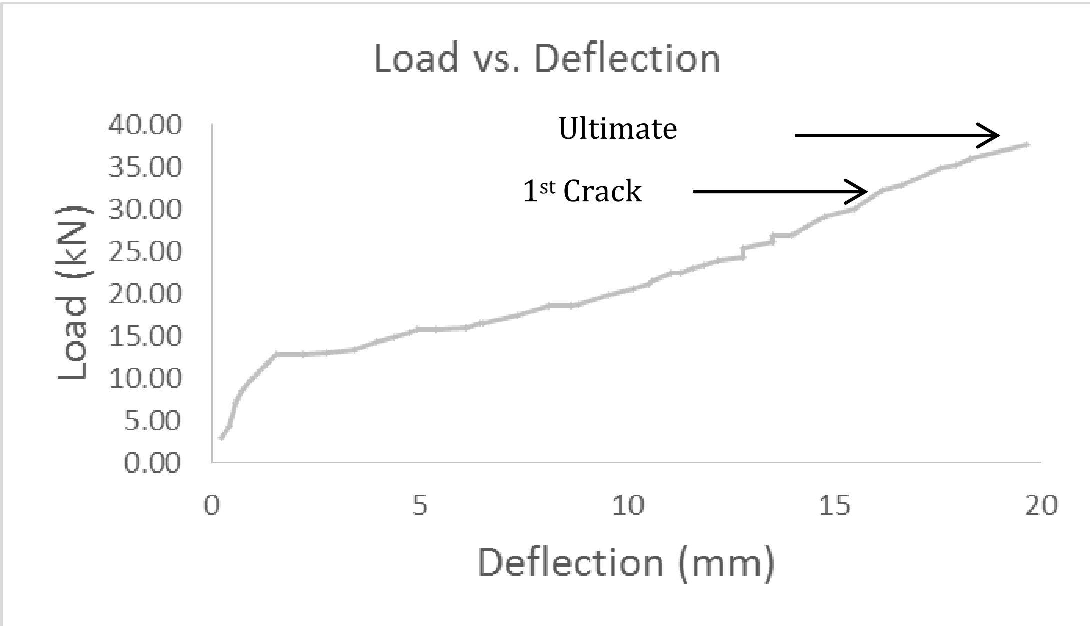

Figure 17: Load Vs. Deflection curve of the actual scale testing

A mix design was done to obtain the required strength out of chip-concrete and 1:2:3 proportion of cement, sand and metal with a water/cement ratio of 0.7 is found to be sufficient to be used in the system.

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PRIORITIZING EFFECTIVE MEANS OF RETROFITTING FLAT SLABS TO MEET PUBLIC DEMANDS IN ORDER TO PROMOTE SUSTAINABLE BUILT ENVIRONMENT

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Abstract: Global warming is one of the major challenges that the current world is facing. Sri Lanka, being a small island, is inevitably undergone by the adverse impacts of it. Hence, it is significant to implement strategies to adapt that, while aiding to mitigation of global warming. In this context, flat concrete roof slabs is a viable option pacifying those two ends. However, it is not so popular among the general public yet and this study was carried out to identify the reasons behind that. It has been found out that Calicut tiles is the most preferred material for roof covering material, particularly due to the thermal comfort that it possesses, over the high initial cost and serviceability issues. Furthermore, flat concrete roofed buildings use, higher amount of energy for active cooling, which is adverse as far as sustainability is concerned. Hence, it is important to retrofit flat slabs so that it is thermally comfortable. In this process, priority should be given to address the issue of thermal discomfort.

Keywords: Global warming, Thermal comfort, Disaster resistance, Energy, Retrofitting flat slabs

1. Introduction

Global warming and associated climate change have been identified as the biggest issues that the world will be facing in the immediate future [1]–[3]. Quantifying that, It has been found out that temperature has risen between 0.40C - 0.80C during the 20th century, and even from that the temperature rise from 1980s is alarming [2]. It has been found out that ten warmest years in last century has occurred in last fifteen years of the century [4], and further, it is estimated that the temperature could rise about 20C - 40C by the end of the 21st century [1].

Global warming itself and the associated climate change has caused many issues to the world, sea level rise being the major of them. The prediction is so that the sea level could rise between 18cm – 59cm during this century [1]. Matsui et al have estimated that for a 50cm sea level rise, Japan itself will lose more than 7500km2 of land, which would influence a population of more than 12.3 million [5]. Other than this, there are some other adverse effects of global warming. Such as,

- The uncertainty climate projections has improved drastically due to global warming, causing many imbalances in many fields, particularly in agriculture [1]
- Temperature rise has increased evaporation of sea water and given more energy to tropical cyclones, increasing the degree of destruction [6]
- Carbonation and chloride ingress are highly influenced by environmental and climatic conditions of the surrounding environment – i.e., atmospheric CO2 concentration, temperature, and humidity [7]. This can reduce the time to failure by up to 31%, or shorten service life by up to 15 years for moderate levels of aggressiveness [8]

Sri Lanka, being one of the smallest islands in the world, is inevitably affected by these adverse scenarios. Hence, it is a wise approach to adapt these as well as contributing to the mitigation as much as possible.

One of the best techniques of adapting to global warming is to make structures robust. For buildings, this can be achieved by flat concrete slabs.

Due to the self-weight of that, the buildings become more cyclonic resistant comparingly [9], [10]. This facilitates a better means of adapting, and further, due to the reduction in embodied and operational energy usage for reconstruction and rehabilitation after a massive natural disaster, this indirectly contributes to the mitigation of global warming as well.

On the other hand, flat concrete slabs can contribute to the mitigation of global warming to a great deal. One of the major reasons to the exponential increase in global warming is the lack of greenery, particularly in urban areas [11]. Multi-storey construction has been identified as a better solution as it provides a higher residential and workable are for a small footprint, of which flat slabs play a major role. In addition, it enables the vegetation to be grown on top as well [12]. Besides, a flat concrete slab increases the lifespan of the structure drastically [13].

However, there are associated drawbacks in this option as well, higher energy consumption for thermal comfort being one of the major among them. Higher energy consumption and subsequent greenhouse gas emission is the major reason for global warming [14], [15]. Generally, buildings account for 40% of total energy usage and 50% of that is used for causing thermal comfort [16]–[21]. Due to the long wave solar radiation of heated slabs, the spaces underneath become more thermally uncomfortable, demanding more energy for cooling in the forms of fans and air-conditioners [22]. This is highly undesirable in the context of sustainability [23], [24]. Other issues those should be under the telescope are, high requirement of capital cost and serviceability issues, particularly cracking.

Those issues have been identified by means of an international literature survey, and the applicability of those into the local context is questionable. Furthermore, it is necessary to prioritize the issues to be addressed if it is attempted to promote flat concrete slabs.

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In this study, a questionnaire survey was carried out to identify the public perspective towards the available roofing materials and their expectation out of selecting a roofing material.

2. Objectives of the study

The main objectives of this study are,

- To identify the preferred roofing material and the reasons for that choice
- To find out the reasons that the roof slabs are not popular among the general public
- To prioritize the issues to be addressed in order to make roof slabs more public
- To identify the issues associated with roof slabs
- To find out the effect of roofing material used to the energy usage for thermal comfort in buildings

3. The sample selected

A sample of 65 has been selected for this questionnaire survey, representing various fields of work and different parts of the island. The distribution of sample is as shown in Figure 1 and majority represents the civil engineers and then research personals and quantity surveyors.

Figure 2 shows the distribution of the existing roofing material of the selected sample. It was found that more than half of the sample uses the asbestos roofing and very less number of people lives in the houses with concrete roof slabs.

It has been observed that even the majority of the people those who have concrete roof slabs currently have it with the intension of future extension. There are hardly any people who intend to use a concrete slab as a roof.

It is very significant to figure out the major reasons for the concrete roof slabs to be not so popular among the public.

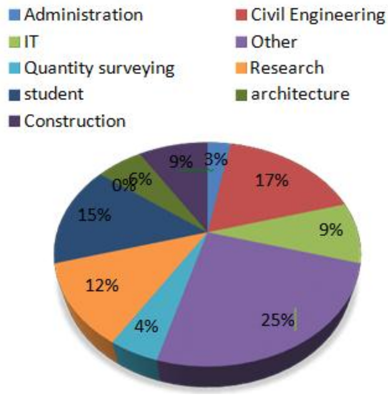

Figure 1: The distribution of field of work

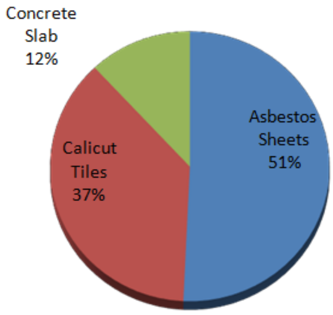

Figure 2: the distribution of the existing roofing material

4. Results

The first question was that whether they are satisfied with their existing roofing materials. The analysis on that of Calicut tile users are shown in Error! Reference source not found. It clearly shows that a vast majority of them are satisfied with what they have. The same analysis for the users of asbestos sheets and concrete slabs are shown in Figure 4 and Figure 5 respectively. It can be clearly seen that those who have concrete slabs as roofs are the people with least satisfaction of what they have.

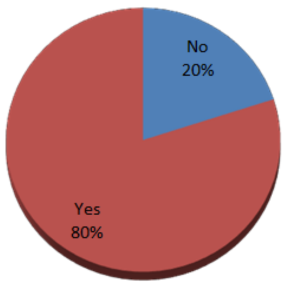

Figure 3: The satisfaction on Calicut tile users on their existing roofing material

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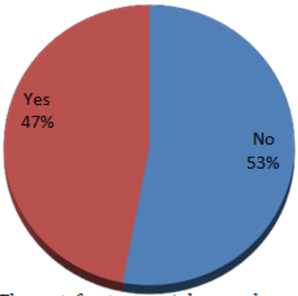

Figure 4: The satisfaction on Asbestos sheet users on their existing roofing material

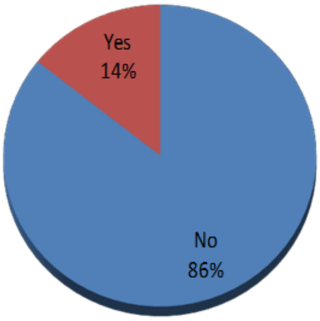

Figure 5: The satisfaction on concrete slab users on their existing roofing material

The analysis on the results obtained for the question 'What is the roofing material that you prefer?' is depicted in Figure 6. Around 75% of the selected sample prefer to have Calicut tiles as their roofing material. Their reasoning behind it is shown in Figure 7 and it was found that the public is more worried about the comfort and aesthetics.

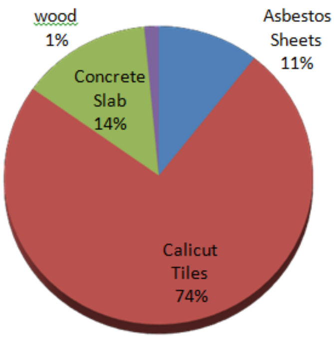

Figure 6: Preferred roofing material of the selected sample

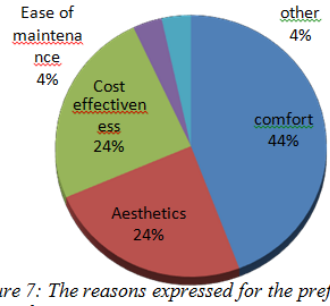

Figure 7: The reasons expressed for the preferred roofing material

Figure 8 and Figure 9 explain the reasons for majority preference on asbestos sheets and Calicut tiles, not concrete slabs. According to the analysis, due to thermal discomfort that feels underneath, had become the key reasons for their adverse thinking on concrete roof slabs. This further proved that, public has more concerned on thermal discomfort than cost.

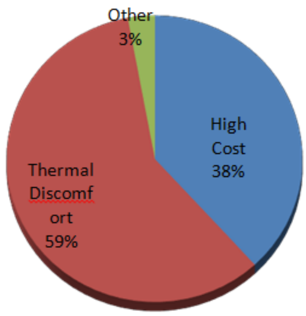

Figure 8: Users of Asbestos Sheets: Reason for not going for concrete slabs

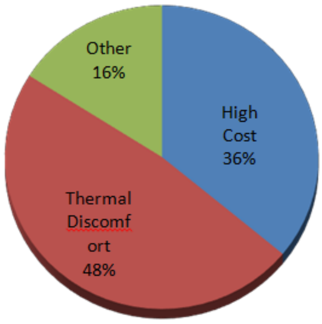

Figure 9: Users of calicut tiles: Reason for not going for concrete slabs

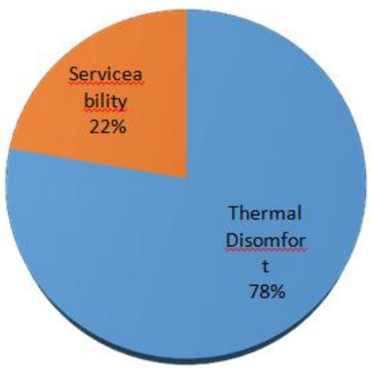

Figure 10: Issues associated with concrete slabs

Figure 10 shows that the issues associated with the concrete slabs at the operational stage. Two major issues have been identified. Thermal discomfort and serviceability issues, particularly cracking. In the operational stage too, thermal discomfort does have a higher impact on the users' minds.

Figure 11, Figure 12 and Figure 13 shows the analysis on user preference on the actions taken to address the thermal comfort. There are two main means that this can be done; active cooling and passive cooling. Active cooling is basically by fans or air-conditioners, which is adverse as far as the sustainability is concerned. Almost 60% of those who have Calicut tiles as their roofing material say that it is sufficient to just open the windows to make the building comfortable. However, 64% of those who have concrete slabs do use active cooling as the increase in air velocity by opening the windows is not sufficient to make the building comfortable.

This is further emphasized by the stats in Figure 14, which shows the number of hours that they use fans daily (in machine hours). It is clearly shown that around one-third of the people who have Calicut tiles as their roofing materials don't need to use fans, whereas those who have concrete slabs use more than nine hours daily.

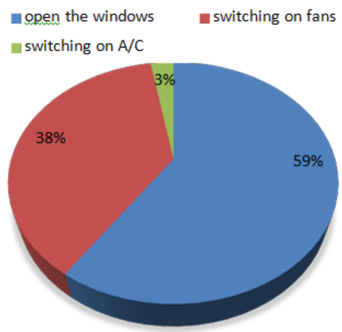

Figure 11: Action for thermal discomfort for those who have calicut tiles as roofing material

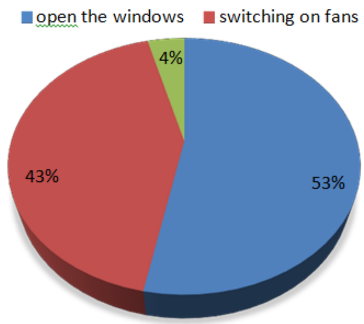

Figure 12: Action for thermal discomfort for those who have Asbestos sheets as roofing material

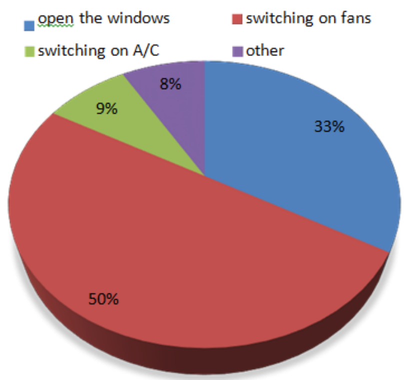

Figure 13: Action for thermal discomfort for those who have concrete slabs as roofing material

5. Discussion

From the above analysis, it was clear that the general public prefers Calicut tiled roofs over asbestos sheets or concrete slabs, mostly due to the thermal comfort that it possesses, due to the clay in Calicut tiles itself acts as a thermally resistive layer and acts as insulation to the building envelope.

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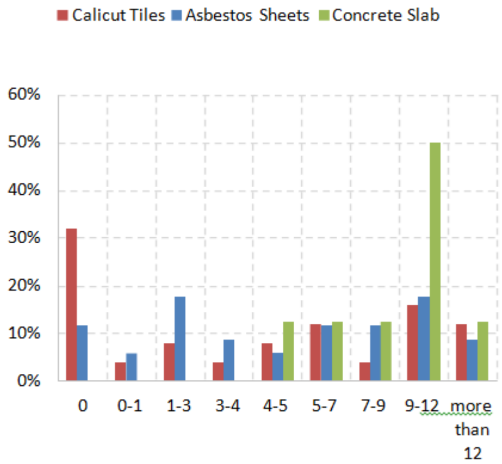

Figure 14: Number of hours that fans are used in homes vs. roofing materials

Furthermore, because of the slope of the roof and orientation, only a portion of the roof is exposed to sun at a time. Consequently, the operational energy of the buildings is much less in Calicut tile roofed buildings than the buildings with concrete slabs.

Nevertheless, it doesn't have many advantages that concrete slabs possess, such as possibility of future extension, possibility of using as a workable space. More importantly, concrete slabs are much durable, which subsequently reduces the energy usage for reconstruction and rehabilitation.

Retrofitting Calicut tiled roofs to gain the advantages of flat slabs or retrofitting concrete slabs in such a way that it is thermally comfortable is much desired in the context of sustainability. Currently, the researchers are focusing on the latter as it seems to be more feasible.

Since, the public is concerning about the thermal comfort than the cost or aesthetics, the best approach in retrofitting concrete slabs is to develop a thermally effective system first and then address for the cost optimization and the aesthetics later.

6. Conclusions

Following conclusions can be made out of this study;

- Out of Calicut tiles, asbestos sheets and concrete slabs, Calicut tiles is the preferred material, dominantly due to the thermal comfort that it possesses.
- There are three major reasons for the concrete slabs to be not so popular, thermal discomfort, high initial cost and serviceability issues, particularly cracking of slabs.
- Among those issues, thermal discomfort is dominant.
- Concrete roof slabs use highest amount of energy for active cooling whereas Calicut tiled buildings use the least among above mentioned three materials
- In retrofitting roof slabs to promote it, addressing thermal discomfort should be given the top priority.

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K. Nandapala, A. Peiris, R. Senavirathna, and D. Nanayakkara, "Investigation of movements in block masonry walls," in Proceedings of the Special Session on Sustainable Buildings and Infrastructure, June 2014.

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INVESTIGATION OF MOVEMENTS IN BLOCK MASONRY WALLS

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Abstract: One of the main concerns in block masonry is cracking, mainly due to thermal and moisture movement. There are some standards which give guidelines and recommendations to control cracking, but these cannot be directly used for local masonry due to the differences in properties of masonry units used, environmental conditions and the construction techniques. This experimental study is mainly carried out to investigate the extent of movement in block masonry and also to find the influence of mortar mix, initial condition of blocks, type of blocks used and wall thickness on movement in block masonry. Sixteen blockwork panels were constructed to study the selected test parameters on movement in block masonry. The movement was monitored for a period of one year, using dial gauges which were permanently fixed to each panel. From the results, it is found that the movement in block masonry is influenced by the initial moisture condition of the blocks. A significant influence of mortar mix and thickness of wall on movement is not seen from the experimental results. It was observed that the movements reached the maximum values within 8 ~ 9 months after construction of blockwork panels. It is found that the highest shrinkage strain of 0.02% is recorded in the masonry panel constructed with saturated solid blocks and 1: 6 mortar mix.

Keywords: Blockwork, movement, cracking, shrinkage strain

1. Introduction

1.1 General

Movement in buildings is one of the main concerns in the construction of modern high-rise buildings. However, in general building construction in Sri Lanka, very little attention is paid in this area due to lack of knowledge. Movements can be caused by many sources [Lenczner, (1981), Alexander and Lawson, (1981), Rainger, (1983), BS5628, Part 3, (1985)]. The main sources of movements are: applied loads on the building, changes in temperature, changes in the moisture content in the material, creep deformations in certain materials, chemical changes in the material, settlement of foundations and dynamic movements. Movements in buildings cause cracking in structural elements which greatly spoils the aesthetic appearance of the building. It is very difficult to permanently repair such cracks, and hence needs regular repairing which increases maintenance cost of the building. The main reasons reported for such movements in buildings are: the use of higher working stresses and slender elements with large spans leads to large movements, combining brickwork and blockwork in construction resulting in differential movements, taller buildings with slender elements cause greater movements, skeletal frame and infill walls cause incompatible movements, thinner sections with lower thermal capacities lead to higher temperature gradients and as large masonry units leads to greater movements at joints as the number of joints are less. Due to these reasons, special care should be taken at design stage to accommodate such movements to avoid displeasing cracks in buildings. This investigation is carried out to determine the movements in block masonry walls, which is needed for the development of specification of movement joints for local block masonry.

1.2 Objectives

The main objectives of this experimental study are:

(i) to evaluate the extent of movement in block masonry; and

(ii) to investigate the influence of mortar mix, initial moisture condition of blocks used, wall thickness and type of blocks used on the extent of movement in block masonry walls.

2. Experimental study

2.1 General

Recognition of the extent of movement in block masonry and the factors affecting the movement of masonry is of importance since it is essential in designing movement joints in masonry structures. Therefore, this experimental study was carried out to investigate the behaviour of block masonry panels.

2.2 Measurement of Movement

Even though it is possible to use available sophisticated techniques to monitor movements in masonry panels very accurately, due to some practical difficulties like high cost and non-availability of facilities to provide uninterrupted power supply over a long period of time, a simple, accurate and less expensive method reported [Nanayakkara, (2011)] was adopted to monitor movements in all block masonry panels. In this method, movements were monitored by using dial gauges which were mounted on masonry panels using steel angles and stainless steel rod. (See Figure 1).

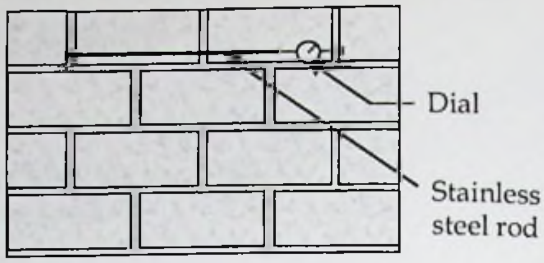

Figure 1: Arrangement used for Monitoring Movements is Masonry Panels

2.3 Main Parameters of the Test Series

Sixteen blockwork panels consisting of two identical panels for each category were constructed to investigate the influence of the test parameters on movements in block masonry. Table 1 summarises the test parameters and similarities in this test series. The four test parameters: the type of block (hollow and solid blocks), mortar mix (1cement: 6 sand and 1 cement : 8 sand), thickness of wall panel (100 mm, 150 mm, and 200 mm) and the moisture condition of blocks at construction (i.e. "Dry"- blocks dried to constant mass in a oven at 100°C, "Soaked"- blocks soaked in water for 30 minutes, and "Normal"- blocks stored in the laboratory for about four weeks were considered in this study. (It should be noted that 150 mm thick hollow blocks were purchased from a different manufacturer.)

2.4 Details of measurement

As described in Section 2.2, movements of blockwork panels were recorded using dial gauges. Initial measurements were taken just after construction and for the first few weeks, readings were taken at frequent intervals. After about two weeks, when the reading was relatively stabilized, readings were taken weekly. Temperature was also recorded in conjunction with the readings of panels, to make the correction for the change in length of the steel rod due to temperature variation.

Table 1: Details of the Panels

Panel Number	Type of Unit	Mortar Mix	Initial Moisture Condition of Unit	Thickness of Panel (mm)
1	Hollow	1 : 6	Normal	100
2		1 : 8	Normal	
3 *		1 : 6	Normal	150
4		1 : 6	Normal	200
5	Solid	1 : 6	Normal	100
6		1 : 6	Saturated	
7		1 : 6	Dry	
8		1 : 8	Normal	
* Blocks from a different manufacturer				

3. Results

From the dial gauge readings recorded, the horizontal strains were calculated for each blockwork panel. Figure 2 to 7 show the variation of shrinkage strains with time for different test parameters. Shrinkage strains are considered as positive in all figures.

From the results of these panels, the following general observations can be made.

- Panels constructed with nearly saturated blocks showed higher shrinkage than panels constructed with dry blocks (See Figure 2). The maximum shrinkage strain recorded was 0.02% in panels with saturated blocks and 0.01% in panels with dry blocks.

- There is no clear indication of any significant influence of mortar mix on movements in block masonry panels (Figures 3 - 4.)

- From Figure 5 it can be seen that the initial rate of drying is higher in thin walls than the 200 mm thick wall. The 150 mm thick wall showed a higher shrinkage strain than 100 mm and 200 mm thick walls. This unexpected result could be due to the influence of difference in the mix proportions used in manufacturing blocks as 150 mm blocks were purchased from a different manufacturer. When comparing 100 mm and 200 mm thick wall panels, there is no clear influence of the thickness of wall on maximum shrinkage strain.

- There is no significant influence of the type of blocks (hollow/solid) used on the movements in block masonry panels (See Figures 6 and 7).

- From the results, it can be seen that all blockwork panels start to shrink just after construction. The maximum shrinkage strains are reached about 8 to 9 months after construction of masonry panels.

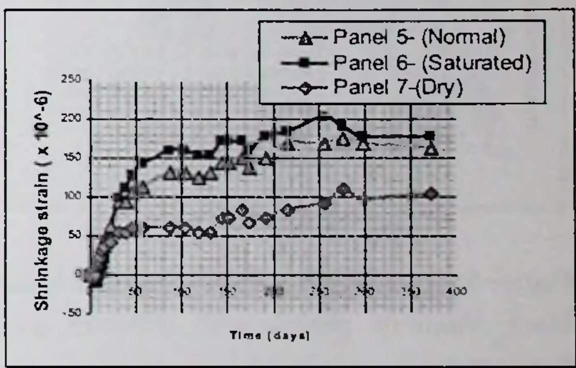

Figure 2: Shrinkage Strain Vs. Time for solid block masonry panels constructed with blocks having different initial moisture conditions.

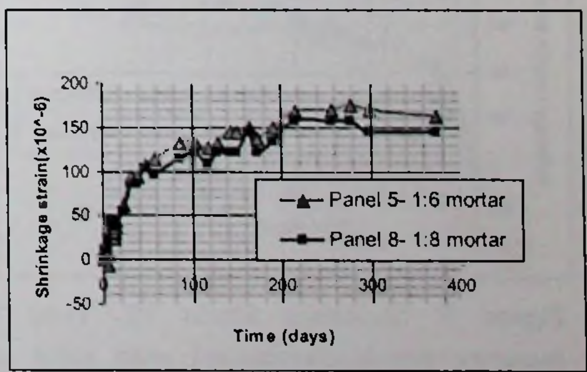

Figure 3: Shrinkage Strain Vs. Time for solid block masonry panels with different mortar mixes.

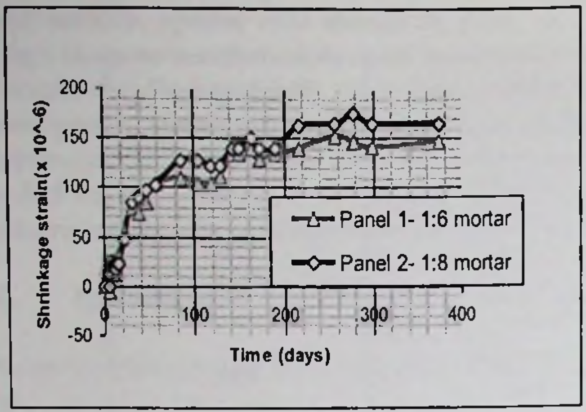

Figure 4: Shrinkage Strain Vs. Time for hollow block masonry panels with different mortar mixes.

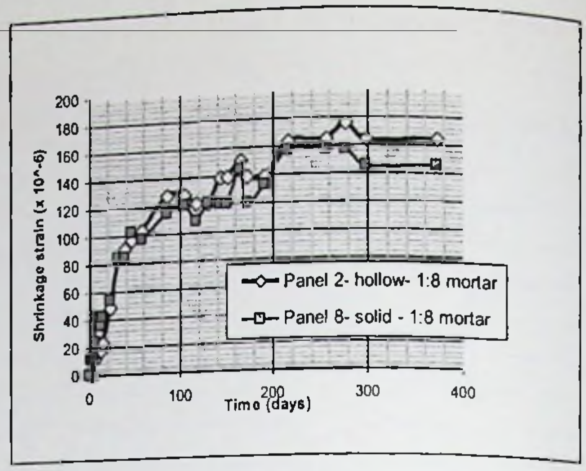

Figure 7: Shrinkage Strain Vs. Time for masonry panels constructed with solid and hollow blocks with 1:8 mortar.

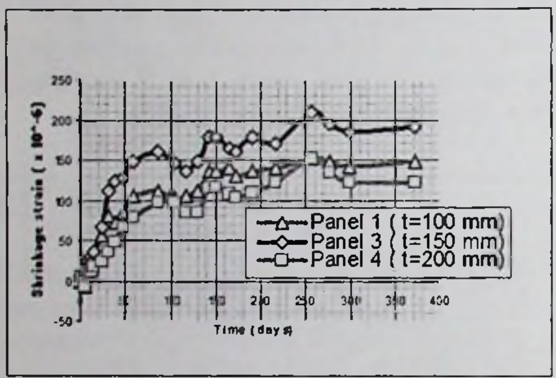

Figure 5: Shrinkage Strain Vs. Time for hollow block masonry panels with different panel thicknesses.

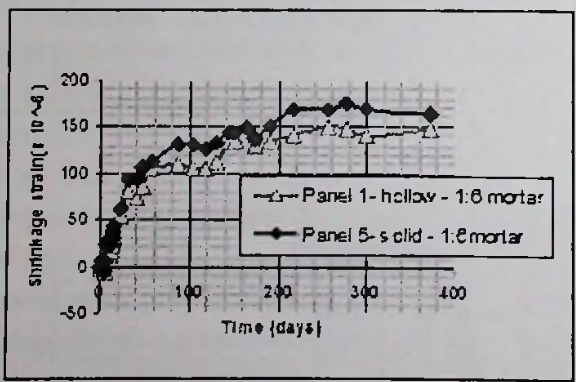

Figure 6: Shrinkage Strain Vs. Time for masonry panels constructed with solid and hollow blocks with 1:6 mortar.

4. Conclusions

- Movements in 16 block masonry panels were monitored over a long period of time till movements are stabilized.
- All block masonry panels shrink continuously, after construction.
- It is found that movements reached the maximum value within 8 - 9 months after the construction of block masonry panels.
- The highest shrinkage strain reported is 0.02% in the masonry panel constructed with saturated solid blocks and 1 : 6 mortar mix and the lowest shrinkage strain is 0.01% in the panel constructed with dry solid blocks and 1 : 6 mortar mix in this series of tests.
- Initial moisture condition of blocks at the time of construction has a greater influence on movement in block masonry.
- To minimize movements in block masonry, it can be recommended to avoid the use of saturated blocks or blocks with very high moisture content.

There is no significant influence of mortar mix, block type and the panel thickness on maximum movements in block masonry panels. However Panel No. 3 constructed with 150mm thick-normal hollow blocks and 1:6 mortar mix showed a very high shrinkage strain (0.02%). This unexpected result could be due to the influence of difference in the mix proportions used in manufacturing blocks as 150mm blocks were purchased from a different manufacturer.

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M P K C Nandapala, R. U. Halwatura, Mitigation of safety issues in telecommunication towers, Proceedings on 4th International Conference on Structural Engineering and Construction Management, Kandy, December 13-15, 2013, pp 34-44.

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28th August 2015

Dr. R.U. Halwatura,
Senior Lecturer,
Department of Civil Engineering,
University of Moratuwa,
Katubadda,
Moratuwa.

Dear Sir,

Subject: International Conference on Structural Engineering and Construction Management - 2013

This is to certify that Dr. Rangika Halwatura has published the following research paper in the International Conference on Structural Engineering and Construction Managementheld from 13th to 15th December 2013 in Kandy, Sri Lanka.

All the articles in this international conference have been subjected to a strict double-blind review process by two independent reviewers, and full papers have been published.

The details of the published article of the above mentioned author are as follows;

> *M P K C Nandapala, **R. U. Halwatura**, Mitigation of safety issues in telecommunication towers, Proceedings on 4th International Conference on Structural Engineering and Construction Management, Kandy, December 13-15, 2013, pp 34-44.*

Thank you,

Yours faithfully,

Prof. Ranjith Dissanayake
Head
Department of Civil Engineering
Faculty of Engineering
University of Peradeniya

……………………

Prof. Ranjith Dissanayake
Co-Chair | ICSECM-2013
Department of Civil Engineering
Faculty of Engineering
University of Peradeniya.

Session 03 **SUSTAINABLE DESIGN** **Session Chairs : Dr. P. Chun & Dr.S.H. Chowdhury**			
Time	**Paper Number**	**Title**	**Authors**
15.30 – 15.50 hrs	SECM/13/227	**Key Paper:** STUDY ON THE GEOTECHNICAL PROPERTIES OF OPEN DUMPS IN SRI LANKA	**U.P. Nawagamuwa** W. D. S. P. Gunaratne P. Kirubajiny T. Thiviya H.K.A. Priyadharshana
15.50 – 16.05 hrs	SECM/13/261	ACHIEVING DISASTER RESILIENCE THROUGH THE SRI LANKAN EARLY WARNING SYSTEM: GOOD PRACTICES OF DISASTER RISK REDUCTION AND MANAGEMENT	**J.K.A.L. Darshaka** A.G.O.A. Chathuranga A.G.A. Wanshanatha W.K.C.N Dayanthi
16.05 – 16.20 hrs	SECM/13/236	SELECTION OF SUITABLE SITES FOR LAND FILLING OF SOLID WASTES USING GIS INTEGRATED WITH ANALYTIC HIERARCHY PROCESS (AHP): A CASE STUDY FOR THE GALLE MUNICIPAL COUNCIL AREA	**Mr. J.K.A.L. Darshaka** A.G.O.A. Chathuranga A.G.A. Wanshanatha W.K.C.N Dayanthi
16.20 – 16.35 hrs	SECM/13/121	MITIGATION OF SAFETY ISSUES IN TELECOMMUNICATION TOWERS	**M.P.K.C. Nandapala** R.U. Halwatura
16.35 – 16.50 hrs	SECM/13/74	EFFECTS OF SURFACE ROUGHNESS ON FLEXURAL PERFORMANCE OF CFRP/CONCRETE COMPOSITES	**M.R.E.F. Ariyachandra** J. C. P. H. Gamage
16.50 – 17.05 hrs	SECM/13/73	INVESTIGATION ON EFFECTIVE USE OF CFRP LAMINATES FOR FLEXURAL PERFORMANCE	**D.M.N. Wijerathne** J. C. P. H. Gamage
17.05 – 17.20 hrs	SECM/13/46	DETERMINATION OF LOAD-SLIP CHARACTERISTICS OF NAILED TIMBER JOINTS	**D.M. Wijesekara** M.T.P. Hettiarachchi W.A.D. Fernando J.A.D.A. Wijayantha
17.20 – 17.35 hrs	SECM/13/271	DEFLECTION RELATED SERVICEABILITY ISSUES IN STEEL BUILDINGS WITH LARGE SPAN GIRDERS	**N.Abeysuriya** M.T.R.Jayasinghe
17.35 – 17.50 hrs	SECM/13/272	TOLL GATES AND TOLL BUILDINGS IN SRI LANKA	**D.S.Hettiarachchi** P.Mendis W.J.B.S.Fernando B.D.Waduge

Safety issues arising in communication towers

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Abstract

The increase in mobile phone use and newer technologies, like wireless email and web access, has created a virtual explosion in tower construction. Even though there are labour legislations in Sri Lanka regarding safety issues still the state of affairs at sites are not favourable enough to safeguard the workers. There are evidences for occurring serious accidents, injuries at a high level in construction sites than in other industries during last few years. This research was carried out to understand the major safety issues in different stages and to create the knowledge among the community on how the people and environment get affected from the tower construction. This was carried out mainly by collection of information and interviews on in house issues and through a survey on communication towers. It was noted that there are key issues, which are not addressed or rather not paid enough attention from relevant authorities, such as regular maintenance of steel structures, identification the role of each stakeholders, inter communication lags, lack of knowledgeable people to manage the after implement work, etc. Based on all the key findings, a safety audit check list was formulated for new and operating towers to improve the quality and safety of the structure.

Key words: Communication towers, safety issues, safety audit, service providers

1. Introduction

The telecommunications industry is experiencing a robust growth on a global scale. By the year 2012, the industry predicts that there will be as many as 4.8 billion mobile phone subscribers worldwide. Since the introduction of mobile phones in the mid-1980s, there has been a significant increase in the number of mobile phone users and installations of base stations. In others, mobile phones are very popular because they allow people to maintain constant and continuous communication without hampering their freedom of movement. This in turn has created a competition between the service providers to provide a better &faster network to the consumer.

As a result of this competition more & more towers are built to have a greater advantage by providing a seamless connection to the wider consumer population. This will lower the safety standards of both tower & workers as found out in the survey. Clients must be concerned not only with the risk to their employees, but also have to consider about the safety of the public in the tower locations. They have to consider the drawbacks of public lawsuits that may arise.

It is also important to avoid or minimize potential damage to properties, from the perspective of public safety. Therefore institutions like Telecommunications Regulatory commission (TRC) are committed to protect public health, safety and general welfare by implementing regulations and guidelines to reduce the impact on environment also.

The construction is the one of the most hazardous among all industries (Jaseiskis, Suazo, 1993). The major causes of accidents are related to the unique nature of the industry, human behavior, difficult work-site conditions, and poor safety management which results in unsafe work methods, equipment's and procedures (Harper, Kohen, 1995). In recent years the construction industry has had a high number of fatalities and high injury rate which is ranking as 3rdworst nationally among industry groups (Construction Industry Council, 2004-2010). Further it cause to economic loss, then to the GDP of the country. Nobuyoshi Yabuki, PetcharatLimsupreeyarat and Tanit Tongthong (Collaborative Visualized Safety Planning for Construction-2010) state the reported cost in construction is billions in dollars in economic loss, the cost exceeds beyond its evidence. Indirect cost of accidents might be as much as six times the direct cost or more.

Falls are a significant public health risk and a leading cause of both nonfatal and fatal injuries among construction workers worldwide. A more comprehensive understanding of casual factors leading to fall incidents is essential to prevent falls in the construction industry (Hinze, Pedersen, &Fredley, 1998).

People are struck by material falling from loads being lifted and material that rolls or is kicked off work platforms; others are struck or buried by falling materials when excavations, buildings or tower structures collapse (Stephen Williams, 1996).

People undergo electric shock and burns when they employ unsafe equipment and overhead power lines and buried cables (Stephen Williams, 1996).

Quality of construction should be maintained in construction projects. Then construction project to be marketable including accident free culture quality of the construction should be maintained. Safety is a major dimension in construction (Baden-Hellard, 1991).

2.0 OBJECTIVES AND METHODOLOGY

Major aim of this report is to identify and discuss the major safety issues and health hazards in different stages of communication tower construction for general public and find solutions for them.

3. Data Collection Analysis & Discussion

Analysis of the following items was carried out which based on tower construction industry. Targeted group in this survey was neighbours in Sri Lankan tower construction industry. Whereas the public survey targeted, the population that has been in contact with tower construction and has been effected by the negligence and improper conduct.

This research was carried out in three districts (Matale, Negombo and Colombo).The questionnaire samples were equally distributed among neighbours who lived around the constructed towers. The analysis and discussion is carried out upon the collected data.

3.1 Data Collection regarding towers.

There are several local and international organisations involved in the Sri Lankan telecommunication industry and the number of towers has increased from 400 in 1990 to over 5000 at present (Table 1).

Name of Operator	Issued date of License	No of towers constructed up to (2011 Dec.)
Etisalat Lanka (Pvt) Ltd	02.09.1988	789
Hutchison Telecommunications Lanka	12.02.1992	421
Mobitel (Pvt) Limited	12.02.1993	713
Dialog Axiata PLC	27.09.1993	1465
Bharti Airtel Lanka (Pvt) Ltd	10.04.2007	927

Table 1: Major telecommunication service providers in Sri Lanka (News in depth-daily newspaper 30-01-12, 11)

3.2 Analysis of the Questionnaire

Complete questionnaire survey was carried out to identified and discussed the effects and causes of poor safety aspects in tower construction industry in Sri Lanka. Out of that, Figure 1.1 shows that 32% located in Matale have communication towers around their radius 1 km. when compared to with Negombo and Colombo this percentage increased 64% and 82% respectively. In Matale 68% people have their communication towers greater than the 1 km distance.

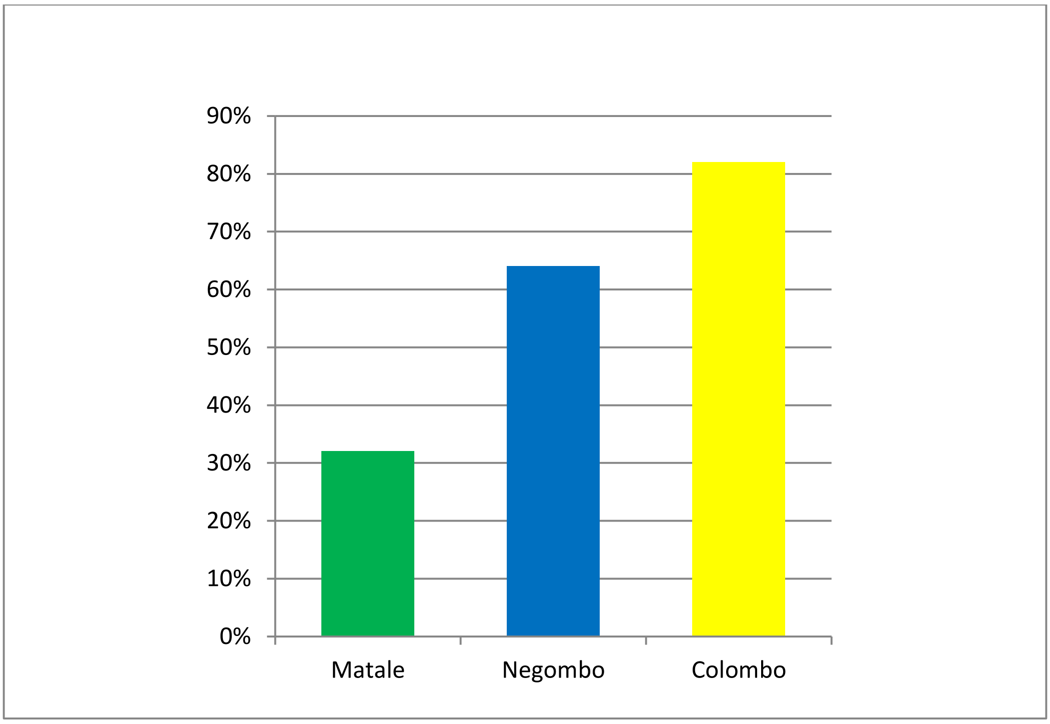


Figure 1.1: Communication Towers located within 1 Km

Figure 1.2 & Figure 1.3 show the personal feelings of communication towers with their satisfactory levels. From that neighbours disagreed and 75% said they are less aware about the communication towers, 55% shows they are neutralized by the service provided by the communication tower. As well as 28% of said they strongly disagree about the service provided by the tower. Less than 10% of agreed the above feelings from the questionnaire.

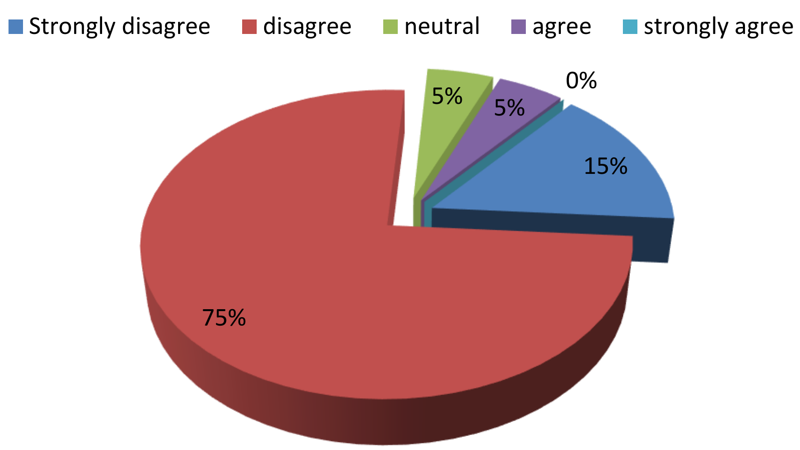


Figure 1.2: awareness of the community of telecommunication towers.

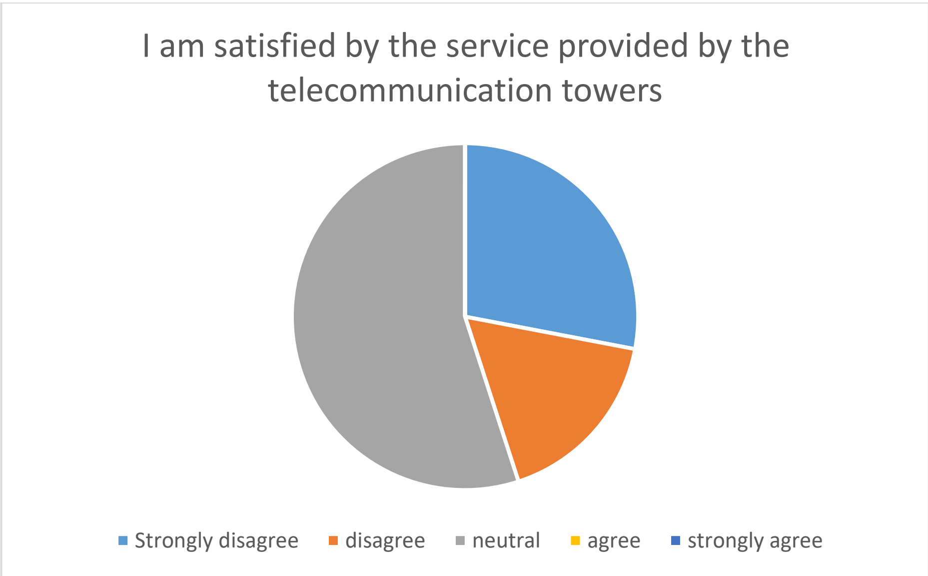
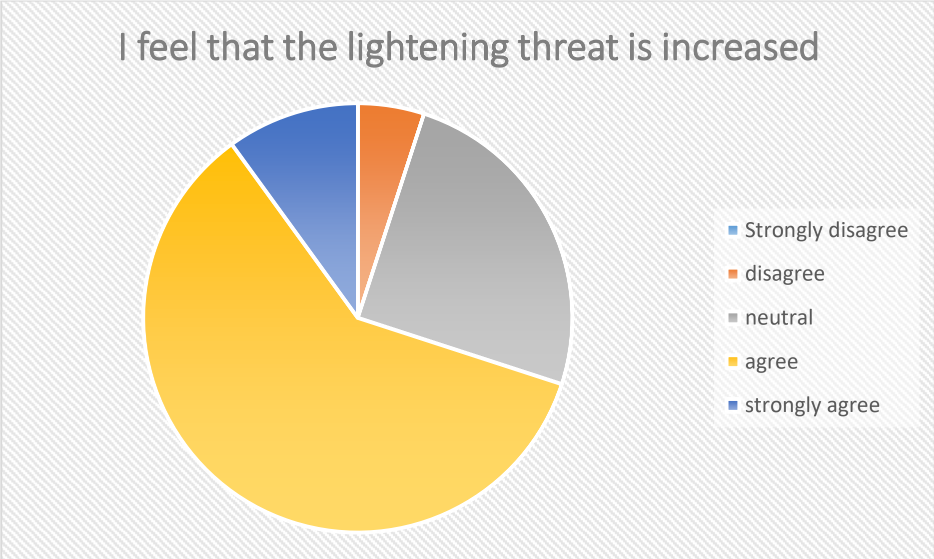
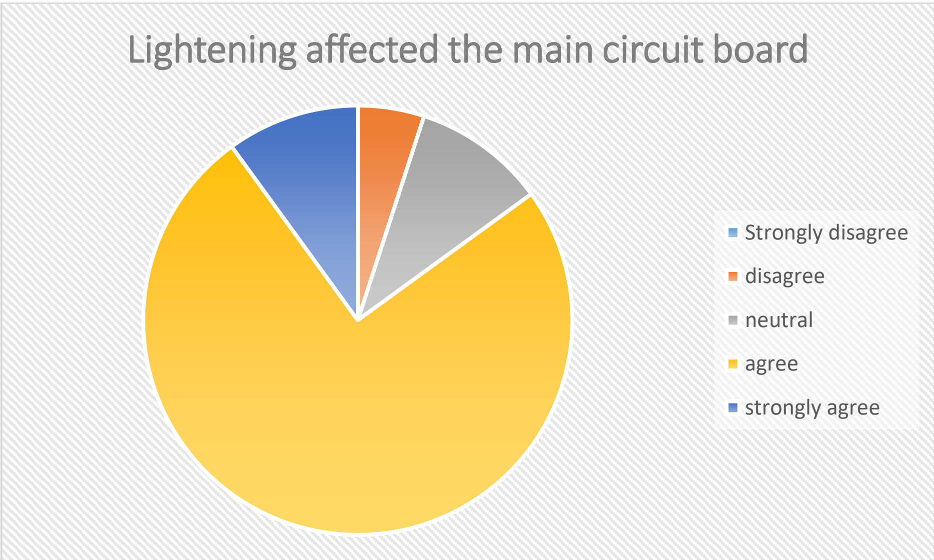


Figure 1.3: Satisfactory levles of the community of telecommunication towers.

From section 1 of questionnaire people show their response to lightning experience after construction of communication towers, this illustrated on figure 1.3.This shows 60% to 75% are agreed that lightning is increased and lightning is affected to main circuit board. 10% shows they disagree with feel that lightning is affected to surrounding trees and 30% neutralized it.





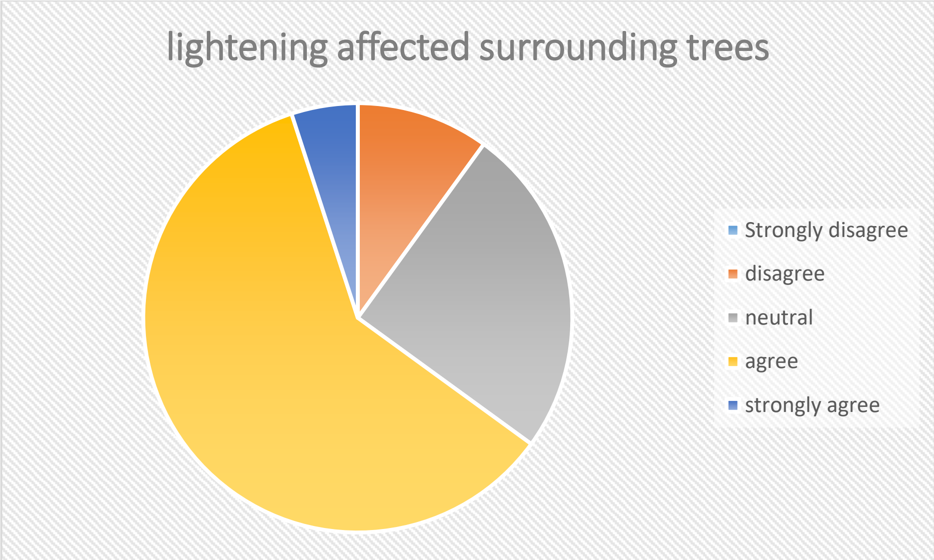


Figure 1.3 Response to lightning experience after construction of communication towers

Awareness of communication towers safety can be identified from section 10 of figure 1.4.This shows that 82 % of neighbours were unaware about the communication towers safety and only 18% agreed with the awareness of communication tower safety.

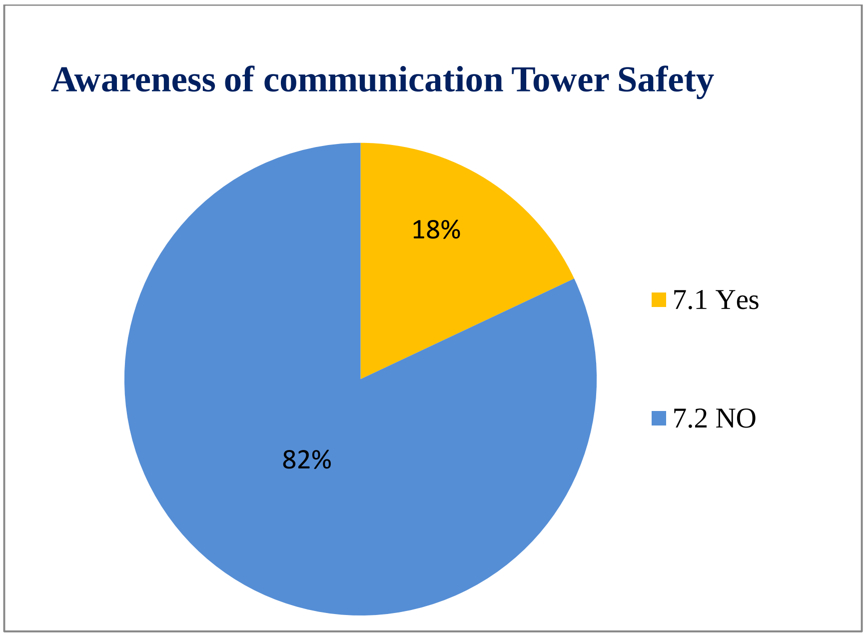


Figure 1.4: Awareness of communication Tower Safety

Health hazards after constructing of communication towers can be identified from figure 1.5. This shows 50 % of asthmatic patient problems raised and 42% are sleepless. Out of that 3% to 5% are having other problems such as headaches and depressions respectively.

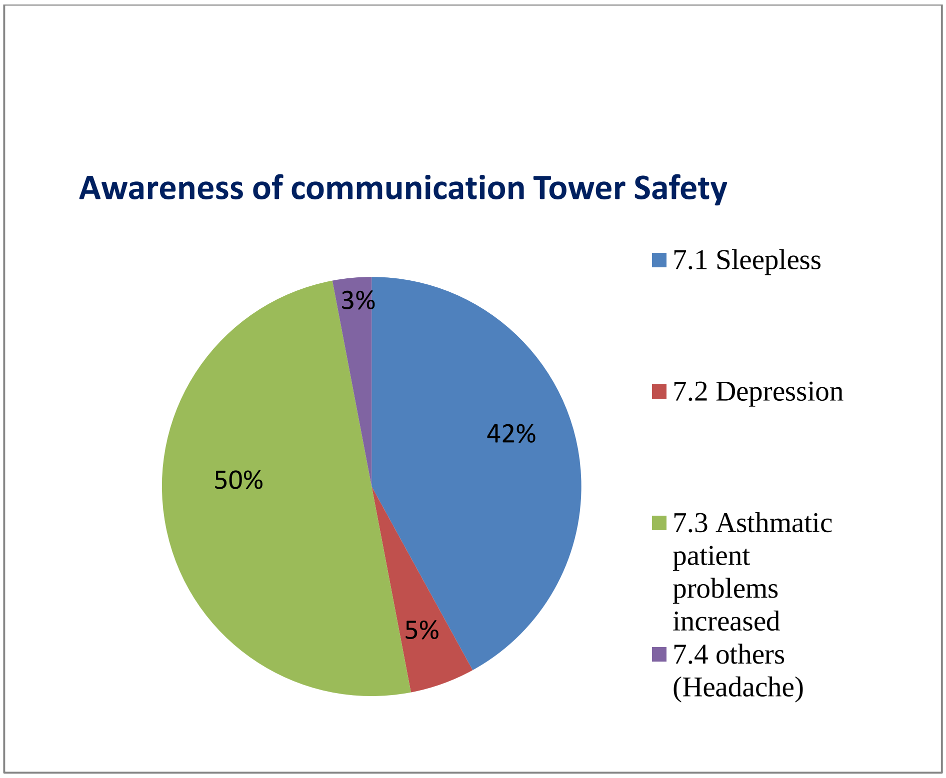


Figure 1.5: Health hazards after construction of communication towers

The knowledge about health and safety policy was come across through the section nine. This illustrates 65% people in Colombo city know about the safety concepts.while the other two cities didn't know about the health and safety policy.

2 Issues of Tower construction industry

Safety issues have been arisen due to the lack of knowledge and carelessness of workers, contractors or surrounding community itself. Here, an in-depth view of the issues from the community's perspective is elaborated through a Relative Importance Index analysis. Results are as tabulated in Table 2.

Identified issue	RII
Not maintaing daily inspection check lists	0.456
Ineffective site keeping such as letting the debris like wooden pallets,steel offcuts to get accumulated at site.	0.476
Neglecting the use of personal protective equipment such as dust masks,respiratory protective equipments,safety goggles and gloves,when using power tools in adverse environments .	0.488
Non arrangement of operating manuals.	0.492
Unavailability of qualified Site supervisors and Safety officers , when works is in progress.	0.496
Failure to arrange hand over meetings with relevant consultants & contractors	0.504
Failure to obtain all guarantee bonds, product warranty etc., from contractor.	0.524
Not incorporating safety & warning signs, fire extinguishers and first aid kits to minimize the damage and increase the awareness of danger against existing hazards.	0.528
Not using of Approved site safety plans.	0.536
Not using of approved quality material at sites.	0.572
Unavailability of hand rails,guard rails and hinged covers in ladderways.	0.576
Not completing the sites in time	0.612
Not barricading any openings through which a person or tools could fall.	0.624
Failure to co-ordinate the progress of commissioning and handover.	0.628
Failure to obtain clearance from supervsor to hoist near high voltage electrical lines or equipments.	0.64
Not issuing final certificates for final inspection.	0.64

Failure to avoid underground utilities and overhead power lines.	0.652
Unavailability of security guards to prevent unauthorized entry to tower construction site	0.668
Use of opearating machineries at unsafe speeds.	0.684
Steps to minimize the accidents prevailing in sites.	0.696
Weekly safety meetings to employees on the project.	0.704
Use of defective tools and equipments.	0.708
Ineffective maintenance at sites.	0.716
Not using of hard hats,long pants,shirts with sleeves required onsite for all workers.	0.72
Not using of approved safety programs required for general contractor and all sub contractors on the job.	0.772

4.0 Discussion of Results

A formal attempt was made to reveal the areas of risks and accidents that could happen (effected by poor safety measures in all stages of tower construction).

According to the findings, the neighbour related problems are the most influencing factor in causing unsafely work condition in Sri Lankan tower construction industry. It followed that the workers have not obtained enough training with regards to safety, and their educational background is not enough to understand the health and safety concepts. As a result the tower construction workers are unwilling to adopt safety measures. Lack of safety instruments at the site, poor site supervision and unawareness of health and safety policy are also some aspects. As project related problems; lack of attention on safety supervision, regular working of more than eight hours. Lack of safety audits, crash project planning and overlapping activities can be considered as next critical factors in stages of tower construction.

This study of questionnaire survey found that Sri Lankan construction experienced various significant effects due to poor safety culture in the tower construction industry and it shows neighbours suffer from the lack of safety for the tower construction activities. They believe lightning is increased due to the construction of communication towers. Finally based on the analysis the results will be discussed upon the factors influencing the poor safety aspects in tower construction industry in Sri Lanka.

The most critical factors found out in the study are violating safety issues in tower construction. Lack of attention on health and safety supervision is also another factor.

Workers and neighbours has not been given enough training with respect of health and safety, the construction workers are reluctant to adopt safety measures, lack of health and safety instruments, poor site supervision, day and night shifts, no safety audits were conducted, unawareness of safety policy.

5. Conclusions

As prescribed at the beginning of this report tower construction industry is one of the most blooming industries in Sri Lanka on today's context. There is a huge competition exists amid the operators. Thus everyone tries to make their market share and the profit.

This study revealed safety is weak in every aspect, in tower construction industry in Sri Lanka. Neighbours haven't got any general knowledge about communication towers. Also they had less awareness about the rules and regulations practised in Sri Lanka.

The findings further illustrate that all the parties involve to constructions, violate the responsibilities on safety aspect in Sri Lankan tower construction industry.

6. Recommendations

Based on the conclusion and discussions of the study, some useful information and a safety audit check list can be suggested in order to diminish the causes and effects of poor safety in tower construction industry in Sri Lanka.

1. Proper lighting protection devicesand painting of Antenna Structures must be in accordance with the specifications of CAASL(Civil Aviation Authority of Sri Lanka)should be installed to safeguard the neighbours.
2. If the antenna mast would cause problems to the public security, disturbance to the neighboring community and problems with the future physical planning purposes of the area, then the developer should agree to dismantle and relocate the facility if so directed.
3. Management of safety should co-ordinate activities of project and ensures that safety is managed by proper supervision to shield neighbours.
4. Management should adapt safety measures to safeguard the neighbours.
5. Management should develop a safety audit check list.A Technical Advisory Committee (TAC) should be appointed by the TRCSL to address any specific issues related to the Antenna Structure Policy.

6. The cumulative Electromagnetic Operating Frequency emission level and output power of an Antenna Structure Farm should be maintained within the limits specified by the International Commission on Non Ionizing Radiation Protection (ICNIRP) and

followed by the Telecommunications Regulatory Commission of Sri Lanka (TRCSL) and MOD (Ministry of Defence).

7. The organization should plan site safety, establish rules, monitor performance routinely by special safety audits appropriate.
8. Government should set up cautious rules and regulations to adapt safety measures in tower construction industry in Sri Lanka.

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CRACK INVESTIGATION AND PROPOSING REMEDIES : A CASE STUDY IN "JEEWAKA" HOSTEL, BORELLA

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***Abstract*—This paper discusses the crack investigation and the proposed corrective and preventive measures for the newly constructed 3-story building named"Jeewaka" hostel in Borella. The building was found to have many cracks, including thermal cracks in the joints between the masonry wall and the RCC (Reinforced Cement Concrete) columns and beams, and shrinkage cracks below the window openings. This paper outlines the type of crack and the cause and suggests preventive and corrective measures to improve building safety and usability. Causes, corrective measures, and preventive measures were taken from expert interviews and analysed using the Delphi technique. According to the findings, it is strongly recommended to provide a chicken wire mesh between the RCC and the masonry joint before starting plaster work. In addition, expansion and construction joints are recommended as good practises. Furthermore, the findings reveal that most cracks under the windows are shrinkage cracks, and it can be recommended to have preventive measures such as providing the sill beam, avoiding the use of rich cement mortar in masonry and by delaying plaster work until the masonry has dried after proper curing.**

***Index Terms*—Thermal cracks, Shrinkage cracks, Structural cracks, Non-structural cracks, Delphi technique, Epoxy grouting**

I. INTRODUCTION

Cracks are a common problem in buildings that can be caused by poor workmanship, faulty construction, age, and natural and environmental causes. They can take various forms, including uniform or varying widths, straight, toothed, stepped, map pattern, or random, and can be found in vertical, horizontal, or diagonal orientations [1]. Cracks may be only at the surface or may extend to multiple layers of materials. Although cracks are subjective, they can indicate a serious defect that could affect the stability and serviceability of the building [2]. Building serviceability is the ability of a building to meet the needs of its users in terms of safety, comfort, and functionality. Cracks in a building can impact its serviceability in a number of ways [3]. They can:

- Allow water to enter the building, which can cause damage to the structure and its contents.
- Allow pests and vermin to enter the building.
- Compromise the structural integrity of the building.
- Make the building unattractive and uncomfortable to live or work in.

For these reasons, it is important to repair cracks in a building as soon as possible. The type of repair that is needed will depend on the severity of the crack and the underlying cause of the crack. In some cases, a simple repair with joint compound may be sufficient. In other cases, more extensive repairs may be required, such as injecting the crack with a sealant or reinforcing the structure with steel rods.

The importance of crack repair in a building cannot be overstated. By promptly repairing cracks, building owners can help to ensure the safety, comfort, and functionality of their buildings for years to come.

"Jeewaka" hostel, a newly constructed three-storey building in Borella, provides hostel facilities for students of the Colombo medical college. However, cracks have been visually detected in several locations of the building, including walls, joints between walls and columns, and wall-beam joints, as well as near the corners of the door and window frames. After two years of service, the appearance of cracks seems to have worsened, potentially causing damage to the building. Nevertheless, the building is a valuable resource for the Colombo medical faculty students, and it is important to protect it to extend its usefulness. The study aims to provide technical solutions to protect the building before it deteriorates further. Cracks may vary from very thin hairline cracks with a width of about 0.01 mm to cracks with a width of more than 5mm. Depending on the width of the crack, the classification is as follows.

- Thin cracks – crack width is less than 1mm.
- Medium cracks – crack width is between 1mm and 2mm.
- Wide cracks – crack width is greater than 2mm [1]

The cracks can be classified according to the direction of propagation such as,

- Vertical
- Horizontal
- Diagonal [4]
- Straight

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- Toothed
- Variable and Irregular [5]

Cracks are found to be divided into two main categories as structural cracks and nonstructural cracks [6]. Structural cracks occur due to reasons such as incorrect design, improper construction, or overload. Non-structural cracks do not have a direct influence on structural weakening of the structures. [7] Non- structural cracks occur because of excessive internal forces developed in the material due to the effects of gas, water content, temperature variation, moisture variation , chemical reactions, etc.

In addition to the above types, the main types of cracks in the building can be categorised depending on the causes of the crack [6]. They are,

- Thermal cracks
- Elastic Deformation
- Shrinkage
- Creep
- Chemical reaction
- Foundation movement and settlement of soil
- Cracks due to vegetation.

There are many methods and techniques that can be used to repair cracks as follows [8].

- Surface Filling Method
- Cementitious Grouting Method
- Epoxy Resin Grout
- Crack Stitching.

II. Objectives

The objectives of this study can be listed below.

- To identify the crack types in the "Jeewaka hostel".
- To identify the causes of the identified cracks.
- To propose the preventive measures and corrective measures for the cracks.

III. Methodology

Cracks in the buildings were identified by a reconnais- sance Survey. In the process, the building inspection was performed to diagnose the cracks in the building, by looking at the entire building from a distance, walking around the building, and inspecting each room to identify the type of crack, measuring each crack in detail and their position in the building. Photographed the cracks and identified the crack type based on shape, and cause through visual identification and knowledge gained by literature review. The fig.1 represent the clear methodology flow chart throughout the case study carried out.

The identified crack types were summarised and a questionnaire was prepared to interview experts in the relevant field of structural engineering to identify the causes, corrective measures and preventive measures of cracks in the identified places. Qualitative data collected by interviewing was analysed using the Delphi technique and Fig.2 shows the methodology of the Delphi technique carried out.

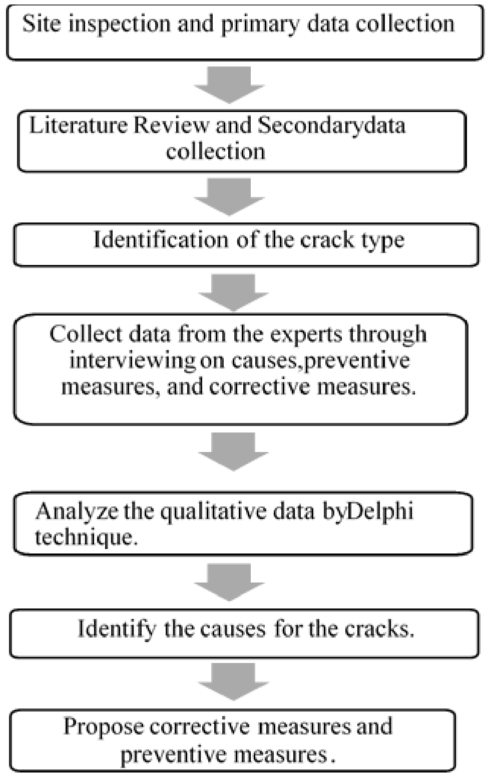

Fig. 1. Methodology flow chart

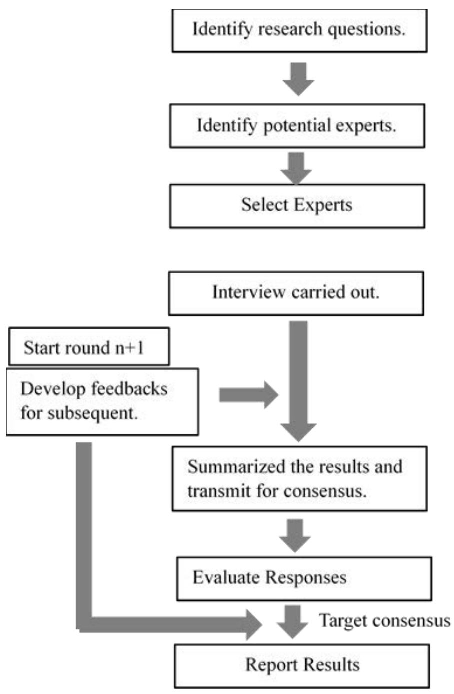

Fig. 2. Carried out Delphi technique

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Fig. 3. Ground floor cracks

Fig. 4. First floor cracks

Fig. 5. Second floor cracks

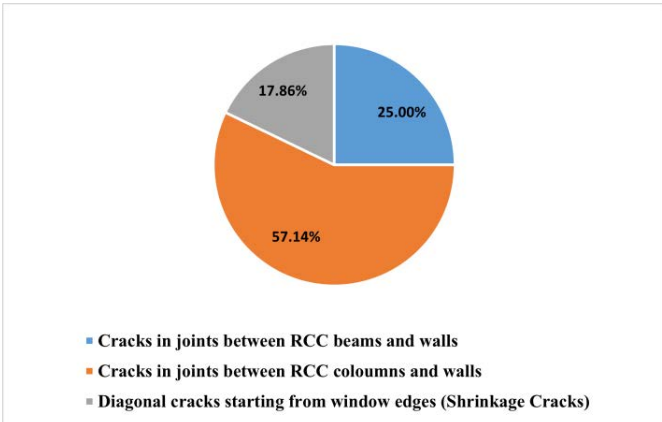

Fig. 6. Crack distribution within the building

IV. Data Collection And Analysis

To achieve these objectives, it is very important to understand the appearance of the building and the locations in which the cracks appeared. Therefore, the cracks were photographed and the floor plans were drawn by numbering the cracks during site inspections. The collected photographs and summarised details are properly arranged and the ground floor crack data are represented by Fig.3 and TABLE I, the first flow crack data are represented by Fig.4 and TABLE II and Fig.5 and TABLE III represent the second floor crack data.

Identification of crack types

According to the above data, it is identified that mainly 3 types of cracks were found in the Jeewaka hostel. They are,

- Vertical cracks at the joint of masonry wall and RCC columns.
- Horizontal cracks in the joints of the masonry wall and RCC beams.
- Diagonal and vertical cracks below the window opening.

According to the literature, it can classified the crack types with relevance to their causes. Therefore, vertical cracks in the joints of the masonry wall and the RCC columns are thermal cracks. Horizontal cracks in the joints of the masonry wall and RCC beams are also thermal cracks. Diagonal and vertical cracks below window openings are shrinkage cracks.
[2] According to the crack classification based on the width of the cracks and based on the primary data collected, all cracks can be classified as 'thin cracks'.

The figure 6 illustrates the summary of crack types within the building and, accordingly, the majority is represented by the cracks between RCC columns and walls, it is 57.14% in percentage.

Identification of causes, preventive measures, and corrective measures for the cracks.

Causes, preventive measures, and corrective measures for the identified crack types were identified by interviewing five structural engineers who are experts in the relative fields. The interviewed questions are as follows in order to carry out the

TABLE I
GROUND FLOOR CRACK DATA

Crack No.	External/ Internal	Crack Type	Structural/Non structural	Width	Location/Description
C1	External	Vertical	Non-Structural	Less than 1mm	Crack in the wall starting from window sill level to down
C2	External	Diagonal	Non-Structural	-do-	-do-
C3	External	Vertical	Non-Structural	-do-	-do-
C4	External	Vertical	Non-Structural	-do-	-do-
C5	External	Vertical	Non-Structural	-do-	-do-
C6	Internal	Horizontal	Non-Structural	-do-	Crack in the wall at the joint of beam and wall
C7	Internal	Horizontal	Non-Structural	-do-	-do-
C8	Internal	Horizontal	Non-Structural	-do-	-do-
C9	Internal	Horizontal	Non-Structural	-do-	-do-
C10	Internal	Vertical	Non-Structural	-do-	Crack in the wall at the joint of the column and the wall
C11	Internal	Vertical	Non-Structural	-do-	-do-
C12	Internal	Vertical	Non-Structural	-do-	-do-
C13	Internal	Vertical	Non-Structural	-do-	-do-
C14	Internal	Vertical	Non-Structural	-do-	-do-
C15	Internal	Vertical	Non-Structural	-do-	-do-
C16	Internal	Vertical	Non-Structural	-do-	-do-
C17	Internal	Vertical	Non-Structural	-do-	-do-

TABLE II
FIRST FLOOR CRACK DATA

Crack No.	External/ Internal	Crack Type	Structural/Non structural	Width	Location/Description
C18	External	Diagonal	Non-Structural	Less than 1mm	Crack in the wall starting from window sill level to down
C19	External	Diagonal	Non-Structural	-do-	-do-
C20	External	Diagonal	Non-Structural	-do-	-do-
C21	External	Diagonal	Non-Structural	-do-	-do-
C22	External	Horizontal	Non-Structural	-do-	Crack in the wall at the joint of beam and wall
C23	Internal	Horizontal	Non-Structural	-do-	-do-
C24	Internal	Horizontal	Non-Structural	-do-	-do-
C25	Internal	Horizontal	Non-Structural	-do-	-do-
C26	Internal	Horizontal	Non-Structural	-do-	-do-
C27	Internal	Horizontal	Non-Structural	-do-	-do-
C28	Internal	Vertical	Non-Structural	-do-	Crack in the wall at the joint of Column and wall
C29	Internal	Vertical	Non-Structural	-do-	-do-
C30	Internal	Vertical	Non-Structural	-do-	-do-
C31	Internal	Vertical	Non-Structural	-do-	-do-
C32	Internal	Vertical	Non-Structural	-do-	-do-
C33	Internal	Vertical	Non-Structural	-do-	-do-
C34	Internal	Vertical	Non-Structural	-do-	-do-
C34	Internal	Vertical	Non-Structural	-do-	-do-
C34	Internal	Vertical	Non-Structural	-do-	-do-
C35	Internal	Vertical	Non-Structural	-do-	-do-

Delphi technique.

1) What is the cause of thermal cracking at the joint of column and wall?
2) What can do as preventive measures for such type of cracking in future works?
3) What can be done as corrective measures for thermal cracking at the joint of the column and the wall?
4) What is the cause of thermal cracking at the joint of beam and wall?
5) What can be done as preventive measures for such type cracks in future works?
6) What can be done as corrective measures for cracking at the joints of beams and walls?
7) What caused the cracking of the shrinkage in the walls below the window opening?
8) What can be done as preventive measures for such type of cracking in future works?
9) What can be done as corrective measures for shrinkage cracking in the walls below the window opening?

The Delphi technique was carried out in 3 rounds.

Round 1 The first questionnaire that was sent to the panel of experts asked for a list of opinions that included experiences and judgments, a list of predictions and a list of recommended activities.

Round 2 As per the above collected data causes, preven- tive measures and corrective measures were summarised and presented for the second round of interviewing to take their agreements and disagreements. Experts were free to provide their consensus or more views on the summary that was generated by the data taken from round one.

Round 3 The summary of round 2 was provided for experts to make their consensus as agree (1), nominal (0) and disagree (-1) by rated the decisions taken in round 2. Then analysed the final output using SPSS software descriptive analysis

TABLE III
SECOND FLOOR CRACK DATA

Crack No.	External/ Internal	Crack Type	Structural/Non structural	Width	Location/Description
C36	External	Vertical	Non-Structural	Less than 1mm	Crack in the wall at the joint of Column and wall
C37	External	Vertical	Non-Structural	-do-	-do-
C38	External	Vertical	Non-Structural	-do-	-do-
C39	External	Vertical	Non-Structural	-do-	-do-
C40	External	Vertical	Non-Structural	-do-	-do-
C41	External	Vertical	Non-Structural	-do-	-do-
C42	External	Vertical	Non-Structural	-do-	-do-
C43	External	Vertical	Non-Structural	-do-	-do-
C44	External	Vertical	Non-Structural	-do-	-do-
C45	External	Vertical	Non-Structural	-do-	-do-
C46	External	Vertical	Non-Structural	-do-	-do-
C47	External	Vertical	Non-Structural	-do-	-do-
C48	Internal	Vertical	Non-Structural	-do-	-do-
C49	Internal	Vertical	Non-Structural	-do-	-do-
C50	Internal	Vertical	Non-Structural	-do-	-do-
C51	Internal	Vertical	Non-Structural	-do-	-do-
C52	Internal	Horizontal	Non-Structural	-do-	Crack in the wall at the joint of beam and wall
C53	Internal	Horizontal	Non-Structural	-do-	-do-
C54	Internal	Horizontal	Non-Structural	-do-	-do-
C55	Internal	Horizontal	Non-Structural	-do-	-do-
C56	Internal	Diagonal	Non-Structural	-do-	Crack in the wall starting from windowsill level to down

frequency charts.

The causes for the identified Thermal cracks between RCC column and masonry wall was,

- Thermal variation causes the expansion and contraction between two different construction materials with two thermal coefficients and due to not providing adequate reinforcement for expansion between the joint, both had 80% consensus in frequency.

The causes for the identified Thermal cracks between RCC beam and masonry wall was,

- Thermal variation causes the expansion and contraction between two different construction materials with two thermal coefficients and due to not providing expansion joints, which both had 100% consensus in frequency.

The causes for the identified shrinkage cracks below the window openings was,

- Concrete shrinks begin to crack due to not providing a sill beam which had 100% consensus in frequency.

The preventive measures for the thermal cracks between RCC column and masonry wall was,

- Chicken wire mesh should be fixed between RCC and masonry joint before commencing plaster work (Chicken wire mesh of 300 mm width should be fixed along the full joint length with nails.) which had 80% consensus in frequency.

The preventive measures for the thermal cracks between RCC beam and masonry wall was,

- Introduced expansion joints and prior to the plastering and fixed a chicken wire mesh between RCC beam and masonry joint which had 80% and 100% consensus in frequency respectively.

The preventive measures for the identified shrinkage cracks below the window openings was,

- Provide a sill beam and application of sound construc- tion practices which had 80% and 100% consensus in frequency respectively.

The corrective measures for the thermal cracks between RCC column and masonry wall and RCC beam, and masonry wall was,

- Epoxy grouting which had 80% consensus in frequency.

The corrective measures for the shrinkage cracks below the window openings was,

- Use fiber mesh with a sealant and plaster on top of that and use of high-pressure flexible polyurethane which had 100% consensus in frequency.

V. CONCLUSION

The potential causes of crack can be controlled if proper consideration is given to the construction material and tech- niques used. Based on this study, using the Delphi technique, it is focused on the main causes of cracks in "Jeewaka" hostel and to propose preventive and corrective measures for the identified cracks. The Delphi technique was carried out in 3 expert rounds to take the final output, and analysis was done using SPSS software descriptive analysis frequency tables.

According to the findings, the cracks in the building could be classified into 3 types. They are thermal cracks at the joint of the RCC column and the masonry wall, thermal cracks between the RCC beam and the masonry wall, and shrinkage cracks below the window openings. Ground floor C1-C5, first floor C18-C21, and third floor C56 occurred due to shrinkage and improper construction practises. The corrective measure is to use fibre mesh with a sealant and plaster on top, and high-pressure flexible polyurethane can also be used. The preventive measure for the above-mentioned crack is providing a sill beam down to the windows and following

TABLE IV
CRACK DATA SUMMARY

Crack no	Description	Crack type	Cause	Corrective measure	Preventive measure
C1-C5, C18-C21, C56	Vertical and Diagonal cracks below the window openings	Shrinkage cracks	Concrete shrinks begin to crack due to not providing a sill beam and bad workmanship.	Use fiber mesh with a sealant and plaster on top of that and high-pressure flexible polyurethane also can be used.	providing a sill beam down to the windows and following, sound construction practices.
C10-C17, C28-C35, C36-C51	Cracks at the junction between RCC column and masonry wall	Thermal cracks	Thermal variation causes the expansion and contraction between two different construction materials with two thermal coefficients and due to not providing expansion joints and bad workmanship.	Epoxy grouting	Chicken wire mesh should be fixed between RCC and masonry joint before commencing plaster work (Chicken wire mesh of 300 mm width should be fixed along the full joint length with nails.)
C6-C9, C22-C27, C52-C55	Cracks at the junction between RCC beam and masonry wall	Thermal cracks	Thermal variation causes the expansion and contraction between two different construction materials with two thermal coefficients and due to not providing expansion joints,	Epoxy grouting	Introduced expansion joints prior to the plastering and fixed a chicken wire mesh between RCC beam and masonry joint

sound construction practises. The ground floor cracks C10-C17, the first floor cracks C28-C35, and the second floor cracks C36-C51 occurred due to thermal variation that causes expansion and contraction between two different construction materials with two thermal coefficients and due to the insufficient reinforcement for expansion in the joints. The preventive measure suggested was that chicken wire mesh should be fixed between RCC and the masonry joint before beginning plaster work (Chicken wire mesh of 300 mm width should be fixed along the full length of the joint with nainails). The corrective measure was epoxy grouting the cracks. The thermal variation of the ground floor cracks C6-C9, the first floor cracks C22-C27 and the second floor expansion and contraction between two different construction materials with two thermal coefficients and due to the inability to provide expansion joints, The suggested preventive measure was introduced expansion joints to plastering and fixed a chicken wire mesh between the RCC beam and the masonry joint. The corrective measure was epoxy grouting the cracks. If we were able to take their preventive measures at the start, we will minimise the cracking problem in the hostel. Therefore, the corrective measures for the cracks were proposed, grouting techniques were proposed to minimise them and propose preventive measures to prevent the crack not occurring again in future construction works. The summary of the final output is illustrated in the Table IV.

VI. Recommendation

There are many types of cracks that can be seen in buildings, and specified corrective and preventive measures are available for them. According to the findings of this project work, it is recommended to have preventive measures for thermal cracks in the joints between the RCC column and the ma- sonry wall, provided that chicken wire mesh should be fixed between the RCC and the masonry joint before beginning plaster work. Chicken wire mesh 300mm wide should be fixed along the full length of the joint with nails. And for the corrective measures, can recommended grouting methods and epoxy injection, stitching, gravity filling, routing and sealing. Preventive measures for thermal cracks at the joint between the RCC beam and the masonry wall can be recommended, such as introduced slip joints, expansion, and construction joints between them and the joints should be designed at the time of planning and should be constructed carefully. Prior to the plastering, a chicken wire mesh was fixed between the RCC beam and the masonry joint. According to the findings, corrective measures can be recommended as grouting methods, epoxy injection, stitching, gravity filling, routing and sealing. The findings reveal that most of the cracks under the windows are shrinkage cracks and it can recommend having preventive measures such as providing a sill beam, avoiding the use of rich cement mortar in masonry and by delaying plaster work until masonry has dried after proper curing. Masonry work carried out with composite cement-lime-sand mortars (1:1:6, 1:2:9, or 1:3:12), which are weak, will have a lesser tendency to develop cracks. It is due to the accommodation of shrinkage in weak mortar of the individual masonry unit. As corrective measures, it can recommended use fibre mesh with a sealant and plaster on top of that.

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Impact of Unexpected Rapid Price Fluctuations on Medium-Scale Building Construction Projects in Sri Lanka: A Case Study

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***Abstract*—The construction industry is facing a severe recession. This scenario spreads throughout the country, and contractors related to the construction industry are critically affected. The general objective of this research is to investigate the variation in material prices in the construction industry and its impact on medium-scale building construction projects. This research investigates the effects of unexpected rapid price fluctuations on the capacity of local contractors. The study concepts are developed through a literature survey to identify relevant variables, and project case studies are used to assess the problem. According to the research; market survey details show that the material price increased dramatically after June of 2021, and these followed a steep upward trajectory until June of 2022. When considering other materials, the price of cement is reduced. Figure 2. Most of the material prices increased above 200% compared to the year 2019. The highest increase in the price of the material is cement and increased to 268% in June 2022 compared to 2019. Not only the material but also the labour daily charges have been escalated, as an example, Blacksmith, Plumber, Specials sk labour and Tinker prices are inflated up to 90% in December of 2022 compared to the year 2019. The results presented by the case studies, collectively demonstrate a pattern of price fluctuation across multiple projects and all the projects which are selected for the case study work, suffered from the price escalation. The project which completion date is falling under the month October in year 2022 (3rd part of 2022), shows the significant price increase.The actual completion dates of projects are significantly delayed compared to their scheduled completion dates and it is the major reason for the price increment.**

***Index Terms*—Price escalation, price indices, construction inputs, price fluctuation**

I. Introduction

Sri Lankan Construction Industry continues to play an important role in the country's economy. Construction industry is one of the most significant industries that contributes to socioeconomic growth, especially in developing countries. The construction sector produces a wide range of products, from individual houses to major infrastructure such as roads, power plants, petrochemical complexes, etc. [1].

The construction industry in Sri Lanka has been growing rapidly for years. According to the Central Bank Report (2016), [2] 'The Sri Lankan Construction Industry contributes 7. 6% to the Gross Domestic Product (GDP), and the value added of construction activities rebounded during the year, recording a substantial growth of 14. 9% in 2016 [3].

But unfortunately, since the end of 2019, it has been shrinking; due to the Covid-19 pandemic situation and the current economic crisis in the country, [4]. According to data from the international trade Administration; "This industry is one of the largest contributors to GDP and the source of employment in Sri Lanka and the construction industry contributed 6.2% of GDP in 2020, [5] from the previous year's contribution of 7.6%, employing around 600,000 workers.

Although GDP decreased by an unexpected 8. 4% in the April-June period in year 2022 compared to the same period last year, acute shortages in fuel and other commodities and prolonged power cuts, which began around February, became more pronounced and brought the economy to a near standstill in June. However, many professionals have lost their jobs as a result of this collapse. Marginal workers were the hardest affected, and their daily activities were hampered by the loss of jobs.

According to the National Construction Association of Sri Lanka;"Sri Lanka's construction sector has collapsed, with approximately 90% of its work stalled in the country, resulting in the loss of around 75% of the workforce, mainly due to the shortage of cement, iron and other raw materials and the high prices of the economic crisis. The construction industry has faced various difficulties, which have hindered the growth of the industry [6]. There are several basic problems in the construction sector, which can be classified into two main categories. The first is related to the consequences of joint planning and execution capability (Mishra and Magar, 2017) [7]. The second problem is the shortage of inputs required for construction and fluctuating market prices.

The deficiencies and fluctuation of the market price of the inputs required for construction greatly affected the growth of the construction industry [8]. Enormous price increases affected to completion of the projects; the contractors couldn't complete their projects within an acceptable margin of time and quality and failed to complete within the planned cost margin, leading contractors to failure.

As a result of this situation, contractors have to suffer significant losses. Due to the losses, construction contractors are facing difficulties building their capacity.

Fluctuations in the price of material pose many challenges and consequences to the construction industry [9]. This phenomenon allows high-end contractors to bid in the non-competitive construction industry. As their economic capacity is greater than that of small-scale contractors, they are able to submit reasonably high bids subject to the prevailing price fluctuations [10].

ICTAD introduced a bulletin of price and cost indices in year 1990 and capitalized it as the base year. Indices can be defined as indicators of inflation in construction inputs such as materials, labour, and fuel [11]. Currently, price indices of 61 items are published including 55 materials (M- indices), 03 labour (L- indices), and 03 Dry Hire Rates for Plant & Equipment (P- indices).

The ICTAD Formula Method for reimbursement of price fluctuation of materials, labour, and equipment in construction projects was introduced in January 1993.The publication is divided into two sections, and Section 1 covers the formula applicable to contracts exceeding Rs.10 million. Section 2 describes the specified method of the Formula Method for contracts not exceeding Rs.10 million. The formula was developed by ICTAD and is the most commonly used method in Sri Lanka, which has been designed to protect both the borrower and contractor from price fluctuations; by allowing the contractors to offer more realistic prices during bidding.

The procurement guidelines (2006) state that a price fluctuation formula should be included in the bidding documents and contract agreements of all Sri Lankan construction projects that are more than three months in duration.The cabinet has granted its approval for the CIDA formula. Due to its inherent characteristics, the government has recommended using the formula as a standard approach in calculating price fluctuations in civil engineering projects [12].

II. Objectives

Price fluctuation in construction input normally occurs in the construction industry, but after the third quarter of 2021,

it was highly affected by the industry. The following factors mainly affected to this issue;

- Increase in taxes
- Lack of raw materials due to restrictions on import of goods.
- A sharp rise in good prices due to the depreciation of the rupee against the dollar.
- Increase in transport charges due to the increase in fuel prices.

The government increases the VAT rate for the import and / or supply of goods or supply of services from 8% to 15% on the 1st of September 2022. Due to this, the prices of goods and services are rocketed. Additionally, the government has temporarily suspended the import of goods related to the construction industry. To remedy this situation, the Cabinet decided to allow the Institute of Construction Training and Development (CIDA) price escalation formula to be applied up to an upper limit of 20% of the contract amount, for contracts beyond 3 months where the price escalation clause has been excluded.

The purpose of this research is to analyze the impact of rapid price variation on medium-scale building construction projects. Projects with a project cost between 10-100 million rupees were selected for the case studies.

According to CIDA notice Gov/CIDA/Directive/110/2022, which was published on November 30, 2021, it discussed the importance of applying price escalation provisions in the construction industry in accordance with the Construction Industry Development (CID) Act 33 of 2014. The Construction Industry Development Authority (CIDA) emphasized the need for including these provisions in contract documents for all Identified Construction Works (ICWs), regardless of the contract duration. This notice clarified that, according to the CID Act, ICW refers to construction work for public use exceeding a value of Rupees Ten Million (Rs. 10,000,000.00), or a higher value set by the Minister. So that, this research is based on the medium scale building construction projects which falling under 10-100 million rupees category.

The main objective of this study is to investigate the significant challenges arising from unpredictable price variations in the construction industry and their impact on project costs.

III. Methodology

This research aims to explore how the capacity of local contractors is affected by unexpected price fluctuations, and it is more detailed and exploratory. Research is based on case studies that help investigate problems and provide knowledge mainly to contractors and other stakeholders in the construction industry. According to the methodology, a flow chart research was done. (Refer to Fig.1)

According to the ICTAD Formula method for adjustments to contract price due to fluctuation in prices; the formula for contracts greater than 10 million is given in Equation (1). The calculation of price escalation for all six case studies was performed using the following formula

$$F = 0.966\,\frac{V - V_{na}}{100}\sum P_x\,\frac{I_{xc} - I_{xb}}{I_{xb}} \tag{1}$$

Where:

F : Price adjustment for the period

V : Valuation of work done during the period concerned

V_{na} : Value of net non-adjustable element

P_x : Percentage cost contribution of input x

I_{xc} : Current index for input x

I_{xb} : Base index for input x

According to this equation, six parameters need to be found to solve it or find the "F" value.

Step 1: Valuation of the work done during period (V)

Valuation of the cumulative work done including 80% of the cost of material delivered to the site but not incorporated in permanent works and deducting the certified cumulative payment up to the previous bill. Equation (2)

$$V = (V_c + M_c) - (V_p + M_p) \quad (2)$$

where,

V_c : Cumulative value of work done during the period in question.
M_c : 80% of the invoiced value of material used for permanent works in the current valuation.
V_p : Cumulative value of work done up to the previous claim.
M_p : 80% of the invoiced value of material used for permanent works on the previous valuation.

Step 2: Excluding the non-adjustable element (V_{na})

The net Non- adjustable element for the current valuation is computed by deducting the cumulative non adjustable element of the previous bill from the current cumulative non adjustable element.Equation (3)

$$V_{\mathrm{na}} = V_{\mathrm{nac}} - V_{\mathrm{nap}} \quad (3)$$

Where V_{nac} is the Cumulative Value of work certified under items specified as nonadjustable element up to current claim, and V_{nap} is the Cumulative Value of work certified under items specified as nonadjustable element up to previous claim.

Step 3: Computation of first part of the Formula

$$0.966 \; \frac{V - V_{\mathrm{na}}}{100} \quad (4)$$

Calculate the next part of the equation.

Step 4: P_x – Input Percentages

Input proportion of a particular input was calculated as the ratio between the cost of the input and the cost of all inputs. The contractor provides these input percentage values for the contract.

Step 5: I_{xb} – Base Indices

'Base Indices' shall be the indices for the input, prevailing for the calendar month, one month before the date set for the submission of the bid. These values are taken from the CIDA statistics bulletin publication.

Step 6: I_{xc} – Current Indices

The current index of a particular input shall be the index published by CIDA for that input for the month applicable. The contractor is supposed to submit the monthly statement for the payment.

For the first interim bill, the current indices shall be taken as the indices that prevail on the first month after the commencement of the contract.

For any other interim claim or the final claim, the current indices shall be taken as indices prevailing for the calendar month, one month after the previous valuation was done.These values were taken from CIDA statistics bulletin publication

Step 7: Computation of second part of the Formula

$$\sum P_x \; \frac{I_{xc} - I_{xb}}{I_{xb}} \quad (5)$$

Step 8: Computation of the total price fluctuation

Multiplying the total obtained in Step 3, Equation (4) and Step 7, Equation (5); and as in the case of any other payment made to the contractor, the amount computed as price adjustment shall be subject to VAT.

A. Data Collection

The target population for this research is local construction contractors. Although price fluctuations are constant, no proper studies have been done on their relationship and impact on the construction industry and especially on construction contractors.

Six case studies of construction projects are used as the research instrument in this investigation. These six case studies are taken from the North Western Provincial Engineering Department-Kuliyapitiya Division. This research work is designed in such a way that it has two parts. The first part deals with market price fluctuation and pricing issues, and the second part deals with compensation-related issues.

Unexpected price fluctuation is a problem that affects contractors of different grades and categories. But because higher-grade contractors take on larger projects, they are more vulnerable to the adverse effects of price fluctuation. Therefore, the study population included in this research work is local contractors of grade C2-C7.

IV. Data Analysis and Discussion

A. Market price Fluctuation Trend

Price fluctuation of construction inputs is unpredictable due to sociogeographical complexity. The price of construction materials fluctuates for a short period of time, but on a quarterly basis, it can be seen that it is consistently increasing at a lower rate. since most construction materials and raw materials are imported; The chain of continuous price changes was found to extend between these quarters. Meanwhile, the labourers have had to grow with the industry, because they have no opportunity to increase their demand.

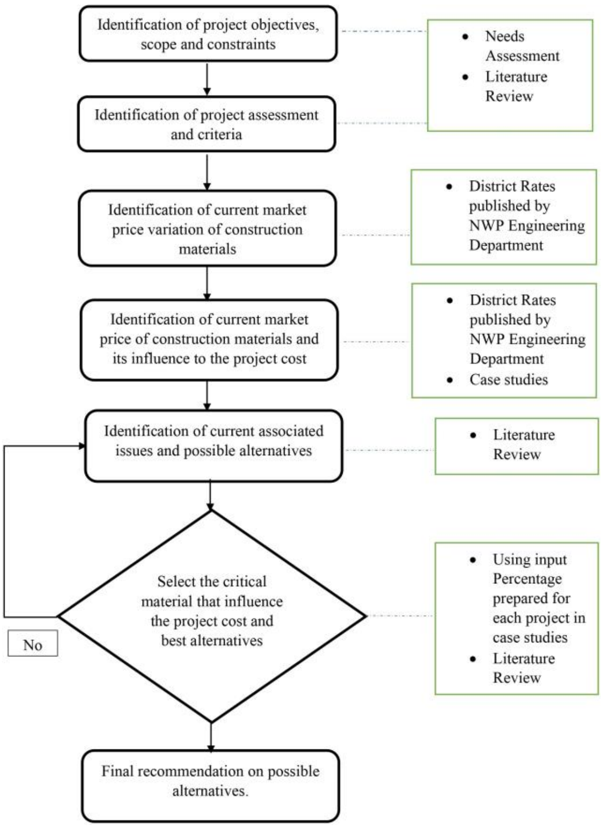

Fig. 1. Flow chart of Research Methodology

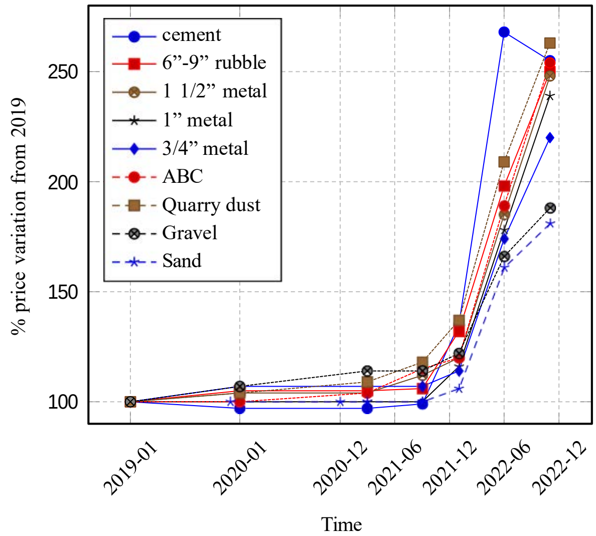

Fig. 2. % Price variation common construction materials compared to 2019

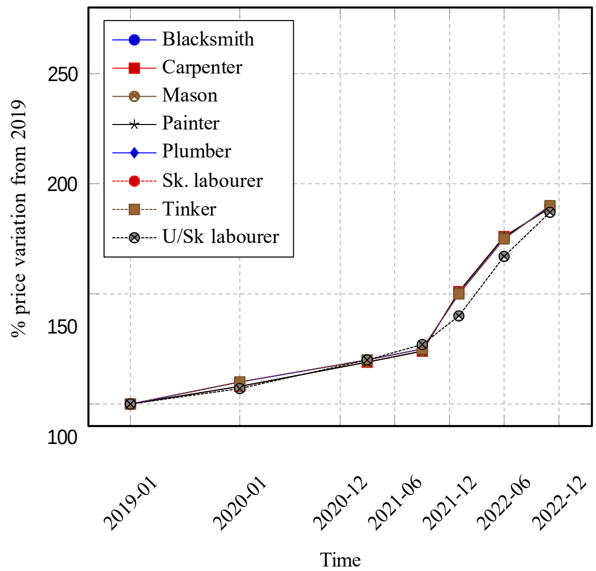

Fig. 3. Price variation graph of common construction materials in comparison to 2019

Since construction is a risky business, contractors must be careful in their bids. i.e., the contractor requires a detailed market survey of the construction inputs, to the preparation of the bid price. Pricing requires not only the market study, but also consideration of all other factors affecting prices such as price fluctuation and contingencies.

According to market surveys, the price variation of the labour from 2019 to 2022 is shown in TABLE I and Fig. 3, the price variation of materials such as Cement, 6”-9” rubble, 1 1/2” metal, 1” metal, 1” metal, ABC, Quarry dust, Gravel and Sand which are directly linked with the construction is shown in TABLE II and Fig. 2. These Tables and Figures are merely used as an example to show the results of the market survey.

B. *Case Studies*

Six case studies were selected to illustrate the level and impact of price fluctuation on the six projects and the construction contractors. All the projects considered for the case study are building construction projects, and the contract amount is within 10-100million.

The study is conducted by collecting data from the projects contract amount, bid date, commencement date, details of the contractor, project basic price indices (input percentage), material requirements, progress reports, material delivery reports and causes of project time extensions. The study focusses on the planned and actual costs of the main inputs in construc- tion projects, which are selected for the study. For building projects, the main inputs are material and labour.Therefore, data is collected from these documents to view the planned and actual cost of the projects for the main inputs of construction of the respective projects.

1) Case study framework: The framework of the case study is organized in four main steps.

- List all the main materials required for the project by input percentage, along with their base prices in pricing.
- Provide the actual purchase price of the materials.
- Analyse the compensation for the project.
- Study the price difference and how it contributes to the contractor’s capacity and project performance.

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TABLE I
PRICE VARIATION OF LABOUR IN COMPARISON WITH 2019

No	Item	Unit	2022 (3rd part)	2022 (2nd part)	2022 (1st part)	2021 (2nd part)	2021 (1st part)	2020	2019
1	Blacksmith	Day	3,800.00	3,500.00	3,000.00	2,500.00	2,400.00	2,200.00	2,000.00
2	Carpenter	Day	3,500.00	3,250.00	2,800.00	2,300.00	2,200.00	2,000.00	1,850.00
3	Mason	Day	3,500.00	3,250.00	2,800.00	2,300.00	2,200.00	2,000.00	1,850.00
4	Painter	Day	3,500.00	3,250.00	2,800.00	2,300.00	2,200.00	2,000.00	1,850.00
5	Plumber	Day	3,800.00	3,500.00	3,000.00	2,500.00	2,400.00	2,200.00	2,000.00
6	Specials sk labourer	Day	3,800.00	3,500.00	3,000.00	2,500.00	2,400.00	2,200.00	2,000.00
7	Tinker	Day	3,800.00	3,500.00	3,000.00	2,500.00	2,400.00	2,200.00	2,000.00
8	U/Sk labourer	Day	2,800.00	2,500.00	2,100.00	1,900.00	1,800.00	1,600.00	1,500.00

TABLE II
PRICE VARIATION OF MATERIAL IN COMPARISON WITH 2019

No	Item	Unit	2022 (3rd part)	2022 (2nd part)	2022 (1st part)	2021 (2nd part)	2021 (1st part)	2020	2019
1	Cement	Cwt	2,462.36	2,588.66	1,300.00	956.00	933.00	933.00	965.00
2	6”-9” rubble	Cu	9,779.00	7,742.00	5,165.00	4,138.00	4,114.00	4,114.00	3,914.00
3	1 1/2” metal	Cu	15,779.00	11,742.00	7,665.00	7,138.00	6,614.00	6,614.00	6,364.00
4	1” metal	Cu	15,779.00	11,742.00	7,665.00	6,638.00	6,614.00	6,614.00	6,614.00
5	3/4” metal	Cu	16,779.00	13,242.00	8,665.00	8,138.00	8,114.00	8,114.00	7,614.00
6	ABC	Cu	16,779.00	12,490.00	7,915.00	7,638.00	6,864.00	6,614.00	6,614.00
7	Quarry dust	Cu	14,779.00	11,742.00	7,665.00	6,638.00	6,114.00	5,864.00	5,614.00
8	Gravel	Cu	6,779.00	5,992.00	4,415.00	4,133.00	4,114.00	3,864.00	3,614.00
9	Sand	Cu	28,000.00	25,000.00	16,500.00	15,500.00	15,500.00	15,500.00	15,500.00

a) Case study -01: Construction of a three-story building with the primary Learning Resource Center & Junior Secondary Laboratory at Holy Angel’s Girls’ College, Kuliyapitiya.

b) Case study -02: Construction of a 70 x 25 ’two-story classroom building in Yayawaththa Mus K.V.

c) Case study -03: Construction of a three-storey 29.25x10.15m classroom building with ordinary-level science laboratory (FF) & library (SF) at Giri / Wildramashila Madya Maha Vidyalaya.

d) Case study -04: Repair of the building at the Giri / Wickramashila National School.

e) Case study -05: Construction of the new laboratory in the Bingiriya Divisional Hospital Bingiriya.

f) Case study -06: Construction of the Katupotha office building of MOH (Bihalpola).

According to TABLE III, it shows the result of case studies. Both contracts (case studies 1 and 2), which had a start date of 2019, have been extended to 2021. Additionally, the contract that started in 2020 must be completed in 2022. The Covid-19 pandemic situation, the lack of contract inputs and the increase in the price of contract inputs can be identified as the reason. Contractors have requested extensions for those projects and the reasons for them are,

- Scarcity of material due to COVID-19 pandemic
- Suspension of the site work due to Covid-19 pandemic
- Due to the difficulty of finding materials
- Due to the difficulty of finding materials
- Scarcity of tiles in the market
- Shortage of fuel
- Material cost increase

contracts concluded in the last months of 2022 (i.e. case study 4,5 and 6) have higher price fluctuations. It is up to 18%-26% compared to the contract amount. Although all the case studies are taken from the kuliyapitiya area, entire country significantly suffered from the price escalation of the construction inputs between year 2019-2022.

With the free float of the rupee, the exchange rate of 1 US $ is Rs.367.00 in December 2022. In December 2020 and December 2021, this was Rs.186.40 and Rs.203.00, respectively. As almost 70% of the construction materials in buildings and other engineering constructions are imported on an import basis, the impact of this would be at least another 60% increase in construction costs.

So this case studies could be applied for all over the country.

TABLE III
SUMMARY OF THE CASE STUDIES

Case study	Contact Duration	Commencement Date	Scheduled Completion Date	Actual Completion Date	Contract Amount (Rs.)	Total project cost (Rs.)	Price Increase (%)
1	365 days	11-Jun-2019	11-Jun-2020	25-Sep-2022	41,613,968.62	44,563,340.21	7.09%
2	365 days	2-Nov-2019	30-Apr-2020	20-Jun-2022	14,000,885.33	14,302,974.72	2.16%
3	365 days	22-Jan-2020	21-Jan-2021	21-Oct-2022	29,127,945.07	30,353,437.80	4.21%
4	365 days	26-Aug-2021	9-Dec-2021	21-Dec-2022	12,001,686.24	14,206,242.71	18.37%
5	365 days	18-Oct-2021	18-Apr-2022	18-Dec-2022	30,330,228.50	35,698,863.73	17.70%
6	365 days	14-Oct-2021	14-Apr-2022	25-Oct-2022	21,472,169.76	27,036,870.10	25.92%

V. CONCLUSIONS

According to this research it shows that price variation can occur at any time; but it is very difficult to predict the magnitude of the price fluctuation, the duration of the fluctuation, or whether it is an increase or decrease in price. Sometimes, even during a period of high price fluctuation, it is often difficult to predict whether the prevailing prices will rise or fall or remain fairly stable.

Price variation means increase or decrease in prices, but in this study it shows that almost all building materials show an increase in price and the prices of some construction inputs are rocketed; due to the contractor's planned construction cost, it will vary at the finishing stage of the project.

Although the construction inputs for civil engineering are quite large in number and type, the Sri Lankan government has allowed compensation for only a few types of materials. According to the ICTAD Bulletin of Statistics, only 55 items are mentioned.

These case studies revealed that contractors were unable to make as much profit as they expected from the projects. Due to insufficient profits, they have not been able to take steps to increase the capacity of the company.

This research shows that project delays are common as a result of material shortages, delaying receiving orders, and loss of working capital. Therefore, contractors try to reduce the quality of the project and materials to minimise their losses; and they try to use materials sparingly by minimising the materials they use.

VI. RECOMMENDATION

To address the challenges arising from unpredictable price fluctuations in the construction industry, it is recommended to enhance price fluctuation forecasting, diversify the compensation system, incorporate risk management strategies, allow flexible bidding mechanisms, promote contractual flexibility, foster collaborative supplier relationships, build contractors' capacity for financial resilience, streamline payment processes, prioritise quality over cost cutting, and advocate for regulatory reform to enable dynamic responses to price fluctuations.

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Mechanical Behaviour of Concrete with Recycled Plastics

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ABSTRACT

The consumption of plastic has grown substantially all over the world as well as in Sri Lanka in recent years and this has created huge quantities of plastic-based waste. Although steps have been taken to reduce consumption of plastic, plastic waste has now become a serious environmental threat to the modern way of living. This creates a substantial amount of garbage every day which is a much unhealthy problem. In order to resolve this problem, recycled Polyethylene terephthalate (PET) flakes were proposed to be used as reinforcement material in concrete. This paper discusses the effect of adding PET flakes to the Ordinary Portland Cement (OPC) to manufacture sand mixed concrete. During this research work, the material properties, and the effect of PET flakes on the compressive strength of concrete were analyzed. Initially, the optimum PET flakes proportion was determined by testing 36 (150mm×150mm ×150mm) test cubes. The optimum plastic flakes percentage was found to be 3.0% and the PET flakes percentage was calculated based on the weight of the cement content of the concrete mix. Grade 20 concrete is proposed with 0.55 water-cement ratio with 3% PET flakes content.

Keywords: *Compressive strength, Manufactured sand, PET flake, Ordinary Portland cement.*

1. INTRODUCTION

The most widely used man-made material in the world is concrete. Buildings, bridges, dams, road pavements, sewage systems, tunnels, waste containment systems, and other structures are built using it. Compressive strength is one of its most significant and desirable properties. As a result, concrete is essential to be designed to develop its maximum compressive strength. (Akinwumi& Gbadamosi, 2014). The significant purpose of this study is to combine a waste material with cement to increase concrete's compressive strength.

Plastic is a worldwide substance that has become an integral component of our modern lifestyle, and as a result, global plastic manufacturing has increased in recent decades. PET is a polyethylene terephthalate (PET) that is often used in the packaging of a variety of items. PET containers are light, clear, and impact resistant, and they do not interact chemically with the contents. They are also non-toxic. All of these traits have helped them establish a strong influence in the polymer market and in the worldwide business. (Liliana Ávila Córdoba, et al., 2013).

The usage of excessive plastic has contributed tremendously to the enhancement of plastic-related waste products, which will be a crucial issue in the future. The reuse of waste and recycled plastic materials in the concrete mix design as an environmentally friendly construction material has drawn the attention of researchers in recent times. (Ghernouli, et al., 2014)

(CEA 2019) revealed that the accumulation of the utilized plastics is a pressing problem, which is considered a major cause of health issues, importantly burning of the plastics, contamination of the soil, water, and air. Further, deterioration of the plastics takes an enormous period of time, and these plastics remain in water bodies, and in soil, which will lead to acute environmental related issues. Recycling

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waste plastics into useful products is one solution to this problem. Many government agencies, private organizations, and individuals have completed or are in the process of completing a wide range of studies and research projects on the feasibility, environmental suitability, and performance of using waste plastics in the construction field, which requires better and more cost-effective construction materials as well as the reuse of waste plastics to save the environment.

(Sandaruwani et al, 2012) identified that similar variation in compressive strength of PET fiber reinforced concrete. Their study revealed that compressive strength increases with increase of fiber content up to a maximum of 1% and then the compressive strength is decreasing with the increment of fiber content more than that. Rathnayaka (2015) conduct an experiment to determine the compressive and tensile strength of PET fiber reinforced concrete and identified that it has been reduced in compressive strength compared to normal concrete but there's an enhancement in tensile strength up to 3% of PET fiber content. However, there is no study on the application of PET flakes with Ordinary Portland Cement (OPC) in concrete road pavements. In addition, several researchers have been carried out preliminary analysis of concrete reinforced and waste polyethylene terephthalate as lightweight aggregate. (N. Saikia and J. de Brito, 2013)

This research paper aims to provide an investigation of the effect of PET flakes as reinforcement material in the Ordinary Portland Cement (OPC) composite. PET plastic bottles, which are extensively used in the Colombo area, were selected as the reinforcing material. During this research work, the material properties, and the effect of PET flakes on the compressive strength of concrete were analyzed. The optimum percentage of recycled plastic has been determined based on an experimental study. The compressive strength of each variant is determined and develop an economically viable concrete mix design using PET flakes. The waste recycled plastic was mixed with OPC mix design by varying proportions (0%, 1%, 2%, 3%, 4%, and 5%) with respect to weight of cement (Saumyasiri & De silva, 2018)

2. AIM AND OBJECTIVES

2.1. Aim

To use Polyethylene Terephthalate (PET) in the concrete structure as inert material and enhance the mechanical properties of concrete.

2.2. Objectives

- To compare the compressive strength of conventional concrete with waste plastic mix (PET flakes) concrete.
- To investigate the optimum PET flakes percentage for mix design

3. METHODOLOGY

3.1 Materials Used

- Clear Color PET (Polyethylene Terephthalate)
- Cement: Ordinary Portland cement (OPC) was used.
- Sand: Manufacture sand which were sieved from 5mm sieve was used.
- Coarse aggregate: 5-20 mm size aggregate was used.

3.2 Pet Flake Concrete Sample Preparation

PET flakes obtained from Viridis Group, Homagama, Sri Lanka was used in the study. PET flakes were added on a weight basis as an inert material. Mix design of concrete was performed according to British (DOE) method (Nevile, 1981). The aggregates were in saturated and surface-dry (SSD) conditions.

3.3 Experimental Procedure

G20 concrete mix was used for these trials. Water-cement ratio was kept constant at 0.55. PET flakes were added as 0%, 1%, 2%, 3%, 4% and 5% of the total weight of the cement content of the mix design as shown in Table 1 to investigate the compressive strength test. The mix design of the concrete mix was illustrated in Table 2.

Table 1: PET Flake Concrete Sample Preparation

Trial No	PET flakes weight (% by weight of cement for 0.025m^3)	Water Cement Ratio
A	0 (Control Sample)	0.55
B	1 (180g)	0.55
C	2 (160g)	0.55
D	3 (240g)	0.55
E	4 (320g)	0.55
F	5 (400g)	0.55

Table 2: Mix Design of The Concrete

Mix Design (1m^3)		For 0.025 m^3
Cement	320 Kg	8 Kg
Water	176 Kg	4.4 Kg
Manufactured Sand	864 Kg	21.6 Kg
Coarse Aggregate	989 Kg	24.73 Kg

The tests of Compressive strength of concrete cubes were performed according to BS EN12390-3:2019 standard, respectively. The load was applied continuously until the specimen failed. Six cubes of (150 mm × 150 mm ×150 mm) specimens were prepared for each mix. The strength of each cube was evaluated after 7, 14 and 28 days, respectively.

Figure 1: Compressive Strength Testing for Cube

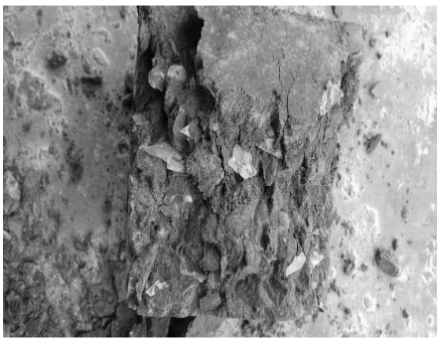

Figure 2: Concrete Cube Specimen in After Testing

4. Results And Discussion

4.1 Variation of Compressive Strength with PET Flake Content

Table 3 shows the difference in compressive strength of concrete cubes with PET flake content. Three specimens were tested, and the average value was calculated. The compressive strength of 3% PET flakes specimens is found to be greater than that of the control specimen. However, increasing the flake concentration further decreased the compressive strength. The results of the compressive strength test are shown in the line graph below. (Figure 3).

In this study, it is confirmed that adding PET flake to the concrete mixture increased the average compressive strength. The addition of 3% gave the maximum compressive strength, irrespective of the period of cure. It is revealed that with higher PET flake content, the workability of concrete was reduced. However, increasing the PET Flake quantity up to 3%, the compressive strength of concrete shows a sudden decrease compared with control samples.

Table 3: Compressive Strength Results for Concrete Cubes

Compressive Strength Test Results N/mm^2						
Percentage of PET flakes	A-0%	B-1%	C-2%	D-3%	E-4%	F-5%
7 Days	14.38	18.49	18.96	19.56	17.02	15.66
14 Days	19.87	24.00	25.95	26.70	23.75	22.02
28 Days	26.00	27.36	30.42	31.22	26.62	25.87

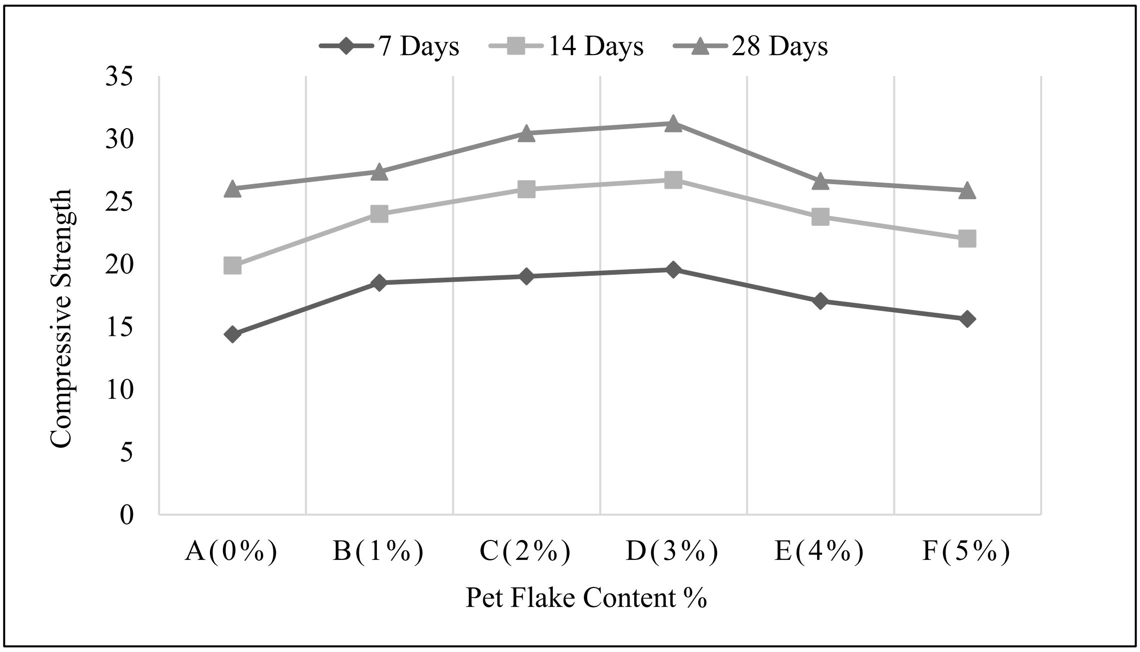

Figure 3: Variation of Compressive Strength with PET Flake Content

4.2 Optimize Mix Design with Optimum PET Flake percentage

From the above observations, 3% PET flake content gives the highest compressive strength results. But this shows that the compressive strength decreases after the plastic exceeds 3%. Two further trials were conducted to make this experiment economically viable. In one mix was tested without PET flakes and in the other only cement was reduced and used 3% PET flakes. There, all other factors were taken to be constant. Comparing the two trial mixes, the compressive strength of 3% PET flake used mix was higher than control mix.

The most commonly used concrete grades by road development authority in Sri Lanka are 20 and 25. Previously used grade20 mix design with normal and economized for road pavement is shown in Table 4.

Table 4: Economize Grade 20 Mix Design

Materials	1st Mix Design without PET(A)	2nd Mix Design with 3% PET(B)
Cement	320Kg	280Kg
Water	154Kg	176Kg
Fine Aggregate	864Kg	864Kg
Coarse Aggregate	989Kg	989Kg
W/C	0.55	0.55
Concrete Density	2349Kg/m3	2287Kg/m3

Compressive Strength of each mix was evaluated after 7, 14 and 28 days, respectively. Figure 4 shows strength details.

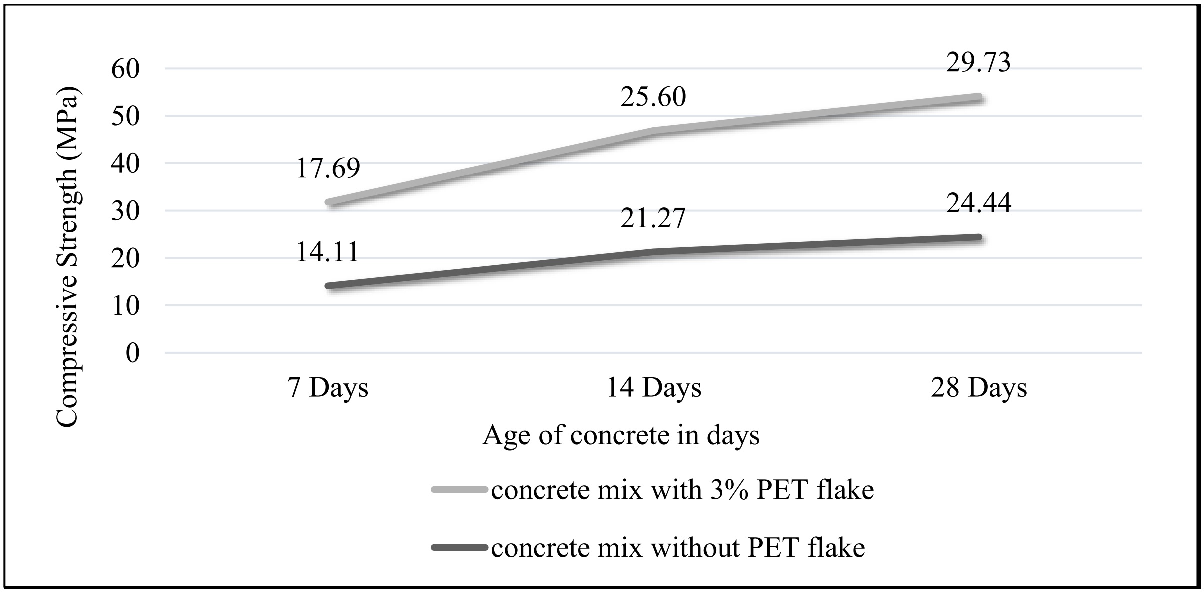

Figure 4: Variation of Compressive Strength with PET Flake Content

According to Figure 4, 3% optimum PET flake concrete sample (B) observed the highest 28 days compressive strength (29.73 MPa) than conventional control sample (A). In addition, by studying this figure can be found that 7 days and 14 days of compressive strength were higher than without PET flake sample. There was significant improvement observed using 3% PET flake with OPC in grade 20 concrete mix design.

5. CONCLUSION

According to the results, this production process, achieves to utilize waste plastic to concrete. By considering the compressive strength of recycled PET flake introduced into concrete and the workability of the mix, 3% PET flake content was found as the optimum value for the design of specimens. Based on the Experimental results, the Compressive strength of concrete is affected by the addition of plastic pieces up to 3% and when it is more than 3%, the compressive strength decreases again.

The ultimate compressive strength for the 3% Recycled PET concrete specimen is higher than the control concrete specimen. As a result, it may be concluded that using plastic in concrete can improve its compressive strength. According to the preceding discussion, it is possible to improve the mechanical properties of concrete by using plastic, which may be used as one of the plastic disposal techniques. 3% optimum PET flake concrete observed the highest 28 days compressive strength (31.22 MPa) without even minor cracks on the concrete surface. Grade 20 concrete was proposed with 0.55 water-cement ratio with 3% PET flakes mix for concrete works as a cost effective and crack minimum concrete. However, further research is needed to better understand the durability of the concrete containing PET flakes.

Furthermore, another important advantage of this research is the ability to create an economical concrete mix design for Grade 20 concrete mix. They were able to reduce the amount of cement in the mix design and considerably reduce the cost per $1m^3$ of concrete. The biggest advantage is that the destruction of the environment from plastic can be minimized.

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Identifying Issues Related to Domestic Plumbing, Corrective and Preventive Measures :A Case Study

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***Abstract*—Plumbing-related issues (Blockages, Leakages, and damages etc.) after construction are common in any type of buildings. Mostly it leads to damage the building structure, water waste,safety issues of users and as unexpected high maintenance cost etc. This study focuses on proposing corrective and preventive measures for common issues in plumbing and sanitary related. As a case study, three site locations that have plumbing problems have been selected in the Western South Department of Buildings, Survey Department, and Foreign Ministry Quarters. The most common issues have been identified by a technical inspection in the above three locations and using the analysis of financial cost usage for past 5 years of time. The main issues highlighted are leaks and damage to pipe fittings, pipes, sanitary fittings, and blockages in waste lines. It was established through a questionnaire that problems with most caused by poor maintenance. Then, corrective and preventive measures have been identified for these issues. Corrective measures have been proposed to repair, replace, and clean chemical blockages. As preventive measures, implementation of planned maintenance mechanism and facilitation of training for plumbers is recommended. Finally, it is recommended to focus more on preventive measures rather than corrective measures to minimise problems and reduce expenses.**

***Index Terms*—plumbing, sanitary fittings, leakages, blockages, relative importance index value**

I. Introduction

Common issues occurring with plumbing (pipe lines, fittings and sanitary fittings) in bath rooms are common problems in buildings. It is vital to provide effective solutions to the problems because we need to minimise water wastage, as we use the same drinking quality water in bathrooms, except for rain or treated water in Sri Lanka, and to avoid damage to the structure of the building and the interior of the buildings [1].

The aim of any construction project is to deliver a successful quality product or service to the client for as long as possible. In that context, the main possible causes of deviating from the aim qualities arise by arising common issues with pipe lines, fittings and sanitary fittings mainly in bathrooms within a very short time after handing over the project [2].

Relevant to this matter, different key main areas were identified as closely focused, such as blocking, leaking, low water pressure, and poor use of pipes and fittings [3]. By collecting data, with a determination of the related problems and reasons, preventive and corrective measures could be introduced and scientifically proposed [4].

In the field, when building or maintaining projects, public and private buildings, houses, apartments, quarters, etc. the main area that can be pointed out is the regular encounter of problems and maintenance related to plumbing problems.

A technical inspection performed has identified common problems in the relevant area and has identified feather and relative plumbing problems by considering the most effective samples from the selected buildings.

When attending and identifying some problems, it was directly relevant to the faults of the clients, consultants, or contractors when doing the construction. If anything related to the prevention method identified during the construction stage, it better to attend to those rather than maintaining time to time after the construction, and has been identified as of the preventive measures for all three main parties to lock forin the study. It has covered selected specified areas under these identifications of issues. The preventive and corrective measures have been listed by summarising them under a particular major category, as has also been carried out in previous literature [5].

II. OBJECTIVES

The main objective of this study is to identify the most common problems with pipelines, pipe fittings, and sanitary fittings in bathrooms. Furthermore, it is intended to introduce effective preventive and corrective measures for these common issues.

III. METHODOLOGY

A. Overall Methodology

Three low-rise government quarters domestic type buildings that have raised the highest number of plumbing-related issues have been selected for the study. The three buildings are;

- The quarters of Survey Department, 150, Bernard soysa Mawatha, Colombo 05
- The quarters of Foreign Ministry, A/1/2, Colombo 05
- The quarters of Department of Buildings, 213,Torrington Avenue, Colombo 07

Initially, a visual site inspection survey was conducted of these buildings to identify the plumbing-related issues of the

TABLE I
DETAIL OF SELECTED OF LOCATIONS

Category	Quarters of Survey Dept.	Quarters of Foreign Ministry	Quarters of DoB
Location	Separately Unit	Inside of a Housing complex	Attached to the Office Building
Located Elevation(from G.L)	6 meters	3 meters	6 Meters
Floor area (m2)	750 Sq.ft	900 Sq.ft	1050 Sq.ft
Distance to O.H Tank	5 Meters	10 Meters	4 Meters
Category of Users	Residential Use for Max.5 Years per each users	-Do-	-Do-
Approx.Age of the Building	40 Years	25 Years	15 Years

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selected buildings, and the main issues have been identified. Then a questionnaire survey was conducted on the occupants to rank the identified issues according to their severity. And a desk study was conducted to analyse the maintenance expenses related issues of these buildings and ranked them accordingly. After finalising the critical issues, preventive and corrective measures are recommended based on the results obtained by an expert interview.

B. Data Collection methods

The method of collecting data for the study was survey-type data collection, and those have been collected as primary data. In that case, both questionnaires and telephone interview tools have been used to collect data from the technical staff for the study.

The Relative Importance Index (RII) was used to analyse the results of the questionnaire survey. The Relative Importance Index is calculated using the formula in Equation 1 [6].

$$\text{Relative Importance Index (RII)} = \sum_{i=1}^{N} \frac{W}{A \times N} \quad (1)$$

Where,

W = the weight given to each factor (1-5)

A = the highest weight = 5

N = the total number of respondents

C. Data Collection

Data were collected with the questionnaire from technical personnel who work in the field. Inspections have been carried out before the preparation of questionnaires to identify causes, corrective, and preventive measures for problems with the support of technical staff from the Department of Buildings. The relevant locations in the selected projects for the study are technically evaluated and recorded. Depending on the selected site areas for the reference source of main inspection to prepare the data collection questionnaire has been implemented for subsequent data collection, the responses have been recorded and the ranking order of the issues has been analysed [2].

The common issues of the related area has identified and recorded to furthermore analyze work. And cost of maintenance data were collected with available reports [7].

Fig. 1. Blockages, Leakages and Damages

Fig. 2. Leakages

IV. RESULTS

A. Results of the Visual Site Inspection Survey

As mentioned above, a visual site inspection survey was carried out to identify the extent of plumbing-related issues in the selected buildings. Figure 1 and Figure 2 exhibit some of the observed issues. Additionally, a list of issues has been prepared at each of the three locations and is presented in Table II.

B. Results of the Questionnaire Survey

The questionnaire survey was carried out to determine the perception of the occupants of each of the identified issues by visual site inspection.

- **Rank 1:** Leakages in pipe fittings
- **Rank 2:** Leakages in sanitary fittings
- **Rank 3:** Leakages in plumbing lines
- **Rank 4:** Leakages in waste lines
- **Rank 5:** Blockages in waste lines

TABLE II
List of Observed Issues in each Location

Location 1	Location 2	Location 3
Leakages in taps and valves	Damages in plumbing line	Damages in plumbing line
Leakages in Water closets	Damages in fittings due to time	Damages in sanitary fittings
Damages in pipe fittings	Leakages in taps and valves	Leakages in Water closets waste line
Damages in sanitary fittings	Blockages in drainage and waste line	
Blockages in waste line		

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- **Rank 6:** Leakages in drainage lines
- **Rank 7:** Damages in sanitary fittings
- **Rank 8:** Blockages in sanitary fittings

By this , it is apparent that leaks in fittings and plumbing lines are frequent and are of high prominence over other issues.

C. Results of the Desk Study Performed to Analyse Expenses

The results of the desk study performed to analyse the expenditure of the identified issues during the last five years are presented in Table III. It presents the percentage of expenditure for each issue for each location, and the totalexpenditure of the particular issue out of the total cost ofmaintenance across the last five years. The ranking given in the table is based on the total expenditure for the given issues. The results show that leaks in fittings and plumbing lines cost more than blockages in sanitary fittings and even damages.

D. Results of the RII analysis on the causes of issues

As the next step, we identified the most probable causes of each of the identified issues and performed a relative importance index analysis to rank and identify the most probable cause to be addressed. The results are presented in Table IV. From the table, it can be deduced that poor maintenance is one of the major causes of plumbing-related problems. Moreover, it is apparent that the use of improper installation techniques is a cause that should not be understated.

V. Recommendations and Conclusions

The most common and critical plumbing problems have been identified in the previous section. As summary, the following five problems have been prioritized in the above analysis.

1) Leakages in pipe fittings
2) Blockages in waste lines
3) Leakages in waste lines
4) Blockages in pipe and sanitary fittings
5) leakages in pipe joints

An expert interview was conducted to identify preventive and corrective measures for the identified problems. Expert recommendations are presented in Table V.

According to the table, it is apparent that the planned maintenance could address most of the common plumbing problems. In addition, it can be pointed out that well training of plumbers would prevent most plumbing-related problemsin buildings. Since the corrective measures are expensive, focusing high on preventive measures is of utmost significance.

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TABLE III
RANKING ORDER OF ISSUES ON SUMMARY OF MAINTENANCE EXPENSES PERCENTAGE (IN LAST 5 YEARS)

S N	Issue	Quarters Location	% out of cost in Locations	% out of Total Cost	Rank order
1	Leakages in pipe fittings	Foreign Ministry Department of Buildings Survey Department	36.9% 20.6% 42.5%	24.6%	1
2	Leakages in sanitary fittings	Foreign Ministry Department of Buildings Survey Department	38.8% 27.2% 34.0%	23.8%	2
3	Leakages in plumbing lines	Foreign Ministry Department of Buildings Survey Department	61.9% 13.7% 24.4%	20.9%	3
4	Leakages in waste lines	Foreign Ministry Department of Buildings Survey Department	13.0% 68.4% 18.6%	10.5%	4
5	Blockages in waste lines	Foreign Ministry Department of Buildings Survey Department	20.9% 34.4% 44.8%	10.3%	5
6	Leakages in drainage lines	Foreign Ministry Department of Buildings Survey Department	50.4% 14.5% 35.1%	3.9%	6
7	Damages in sanitary fittings	Foreign Ministry Department of Buildings Survey Department	43.6% 43.6% 12.8%	3.5%	7
8	Blockages in sanitary fittings	Foreign Ministry Department of Buildings Survey Department	23.3% 34.9% 41.9%	2.4%	8

TABLE IV
RESULTS OF THE RELATIVE IMPORTANCE INDEX ANALYSIS CARRIED OUT TO RANK CAUSES FOR MOST COMMON ISSUES

Type of issue	**Cause**	**RII value**	**Rank**
Leakages in pipe fittings	Use fewer quality brands for fittings Poor maintenance Use incorrect installation techniques for fittings Use incorrect methods of laying pipes Use improper methods for jointing pipes	0.80 0.72 0.57 0.33 0.30	1 2 3 4 5
Blockages in waste lines	Poor maintenance Use incorrect installation techniques for fittings Use fewer quality brands for fittings Use incorrect methods of laying pipes Use improper methods for jointing pipes	0.85 0.77 0.70 0.50 0.30	1 2 3 4 5
Leakages in waste lines	Poor maintenance Use fewer quality brands for fittings Use incorrect methods of laying pipes Use incorrect installation techniques for fittings Use improper methods for jointing pipes	0.86 0.76 0.64 0.54 0.35	1 2 3 4 5
Blockages in the pipe and sanitary fittings	Use fewer quality brands for fittings Poor maintenance Use incorrect installation techniques for fittings Use improper methods for jointing pipes Use incorrect methods of laying pipes	0.83 0.77 0.70 0.58 0.32	1 2 3 4 5
Leakages in pipe joints	Use improper methods for jointing pipes Use incorrect methods of laying pipes Poor maintenance Use fewer quality brands for fittings Use incorrect installation techniques for fittings	0.84 0.73 0.56 0.53 0.36	1 2 3 4 5

TABLE V
SUMMARY OF CAUSE, CORRECTIVE AND PREVENTIVE MEASURES FOR COMMON ISSUES

Identified common issues	Reasons for the Issues	Corrective Measures	Preventive measures
Leakages in pipe fittings	Use fewer quality brands for fittings Poor maintenance Use incorrect installation techniques for fittings	Repair leaks on pipe valves and taps Replace damaged parts of the fittings	Use correct installation techniques for fittings Use best quality brands for fittings Well maintenance
Blockages in waste lines	Use fewer quality brands for fittings Poor maintenance Use incorrect installation techniques for fittings Use incorrect methods of laying pipes	Repair leak joints on pipe lines Replace the pipe line newly	Use correct installation techniques for fittings Use quality brands for fittings Well maintenance
Leakages in waste lines	Use fewer quality brands for fittings Poor maintenance Use incorrect installation techniques for fittings Use incorrect methods of laying pipes	Repair and Replace damage parts of the fittings	Use best quality brands for fittings Well maintenance
Leakages in sanitary fittings	Use fewer quality brands for fittings Poor maintenance Use incorrect installation techniques for fittings Use incorrect methods of laying pipes	Repair damaged parts of the fittings Replace damaged parts of the fittings	Use correct installation techniques for fittings Use quality brands for fittings Well maintenance
Leakages in plumbing lines	Use fewer quality brands for fittings Poor maintenance Use incorrect installation techniques for fittings Use incorrect methods of laying pipes	Repair leak joints on pipelines Replace damaged parts of the fittings	jointing pipes Use proper methods for Use correct methods of laying pipes

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2.4.2

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CONTEMPORARY AND COMPARATIVE STUDY OF CUSTOMS AND BELIEFS IN HOUSE CONSTRUCTION

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Although this is an era with marvels of Science and Engineering, the shadows of customs and beliefs of diverse fields are still followed in different levels. It is evident that a considerable number of customs and beliefs in house construction are yet followed by people in countries like Sri Lanka, India and China. In this study, contemporary status and reasons behind admitting those beliefs were investigated through a questionnaire survey carried out among the main stakeholders of the construction industry. A sample of 210 individuals consist of 75 Civil Engineers, 45 Architects, 30 Astrologers, 30 Carpenters and 30 Masons were randomly selected for this study. The study revealed that 68% of respondents are believed in customs and beliefs while 32% disregard. 41% of Civil Engineers, 27% of Architects, 97% of Astrologers, 100% of Masons and 97% of Carpenters are believed in customs and beliefs. As specific responses of respondents, 81% opted not to erect three or more aligned openings and not to place wall plates, rafters or beams directly on top of the openings, 75% of respondents have no willingness to place more west facing doors and windows while 73% respondents reluctant on cross wall junctions in brick walls. The study revealed that, though Masons, Carpenters and Astrologers adopt those beliefs as they inherit them from generation to generation which are being startled of their occult grab, Civil Engineers and Architects believe on these with some understanding in Engineering concepts. It divulged that when the people become more educated they tend to discard traditional beliefs in building construction and deal with some knowledge on Engineering and Scientific concepts.

Keywords: *residential buildings, mini commercial buildings, customs and beliefs*

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2.4.2(2)

Madujith Sagara Chandra, Kasun Nandapala, Buddhika Weerasinghe: The impact of aligning three or more openings in a dwelling, anengineering perception using fluid dynamics. 10th International Research Conference, General Sir John Kotelawala Defence University, Rathmalana, SriLanka; 08/2017

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10TH INTERNATIONAL RESEARCH CONFERENCE

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'Changing Dynamics in the Global Environment: Challenges and Opportunities'

ABSTRACTS

General Sir John Kotelawala Defence University Sri Lanka

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THE IMPACT OF ALIGNING THREE OR MORE OPENINGS IN A DWELLING: AN ENGINEERING PERCEPTION USING FLUID DYNAMICS

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Abstract – In spite of the fact that this is an era with significant innovations in building construction, the shadows of customs and beliefs of building construction are still followed in various levels. These beliefs play a major role in residential and mini-commercial building construction, mostly in countries like Sri Lanka, India and China. In this study, a selected belief in building construction, "Not having three or more aligned openings along same row" was investigated and the engineering significance of the belief was investigated by means of fluid dynamics simulations carried out with Autodesk Flow Design, Computational Fluid Dynamics (CFD) software. The results of CFD simulation showed that, the wind entered the house in one end, moved through aligned openings as a rapid flow making the air distribution to other parts of house less than 15% of total flow, but when the openings were not aligned (staggered openings) there was adequate air circulation to other spaces of the house. Finally, it was proven that the concept, "Not having three or more aligned openings along same row" is technically rational and there is an Engineering significance of it.

Keywords– residential buildings, mini commercial buildings, customs and beliefs, computational fluid dynamics.

2.4.2(3)

Madujith Sagara Chandra, M.R.D. Madumal, Kasun Nandapala, R.U. Halwatura: Feasibility of Rainwater Harvesting Systems for The Water Utilization of Landscaping Projects in Sri Lanka, International Conference on Water Security Through Rainwater Harvesting, Colombo, Sri Lanka, 29/11/2018

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INTRODUCING RAINWATER HARVESTING SYSTEMS FOR THE WATER UTILIZATION OF LANDSCAPING PROJECTS IN SRI LANKA, BASED ON A CASE-STUDY AT WAYAMBA UNIVERSITY

Madujith Sagara Chandra[1], M.R.Dasitha Madumal[2], Kasun Nandapala[3], R.U.Halwatura[4]

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Abstract

The scarcity of water is one of the main issues which the whole world is currently confronting. In such a situation, using potable water on behalf of landscaping projects can never be encouraged. In this study, rainwater harvesting method which can be seen under the category of sustainable development was proposed for the water demand of landscaping projects.

The selected case study is an actual project proposed for the Wayamba University, Sri Lanka which consists a landscaping project of 7.3 Acre where the monthly water demand is about 701m^3. On behalf of water demand of landscaping, a rooftop rainwater harvesting system covering about 718m^3 minimum monthly rainwater harvest using a roof area of 6000 m^2 was proposed. Since there is a balance of 17m^3 collectable water, the expected water demand can be effectively fulfilled. The rainwater storage tank suitable for the expected project was proposed to be imported from Australia (BlueScope steel water tank) or proposed to be built meeting same quality in Sri Lanka.

The proposed system which recovers the project cost in 7.2 years, serves a considerable amount of financial benefits and solutions for wastage of water as well as usage of potable water on behalf of landscaping requirements. Since the proposed system can be effectively used for the desired goal of landscaping, the same system can be proposed for the other universities in Sri Lanka as well as the foreign universities. This can be used not only for the landscaping projects but also for the day-to-day purposes such as gardening, washing and flushing purposes. As the next stage of the project, the same type of a model can be effectively used for the fulfilment of potable water demand adding specific water purification methods.

Introduction

The water demand of a landscaping project is usually fulfilled by normal city water supply which delivers the purified water in potable condition. Using potable water for gardening purposes is a real disaster. But in fulfilling of water demand of such activities, natural rainwater can be used through an effective rainwater harvesting system. This study reveals the feasibility of utilizing rainwater on behalf of the landscaping projects using an actual case study from Wayamba university, Sri Lanka.

Calculations

Rainfall calculation

Harvestable rainwater amount (m^3) is given by;
Roof top area (m^2) × Average monsoon rainfall (m) × Runoff coefficient
Roof top area = 6000 m^2
Runoff coefficient = 0.9
Average monsoon rainfall;
from the data of Meteorology Department = $\frac{0.3 \times A}{5} + \frac{0.7 \times B}{5}$
Where; A is 2007-2011 rainfall water harvested and B is 2012-2016 rainfall water harvested
Minimum average monthly rainfall harvest = 718 m^3

Water usage calculation

Total landscaping area = 7.3 Acre
Water demand per 1 perch = 10 litre x 2 [Per day (2 times)]
Total water usage per Month = 10 x 2 ×160 × 7.3 × 30 = 700,800 l = 700.8m^3

Project cost calculation

As the rainwater storage tank, XL 45-R7 tank was proposed to be imported from BlueScope steel water tanks, Australia. Project cost was calculated with respect to that storage tank (tank cost with shipping has been used, 1 USD = 150.00LKR). VAT of 15% and NBT of 2.04% has been added in total cost.

Cost of the tank = 9,000 USD
Transport and installation cost = 345,000.00 LKR
Total project cost = (9000x150) + 345,000 = 1,695,000.00 LKR
Total project cost with Taxes = (1,695,000×1.0204) ×1.15 = 1,989,014.70 LKR

Figure 1. Considered Landscaping program

Figure 2. Location of the storage tank near gymnasium

Benefit Cost Analysis

The objective of the benefit cost analysis was to find the project recovery period.
Average water consumption = 700.8 m^3
1 water unit = 2.83 m^3
Average water units per month = 700.8/2.83 = 247.63 units
According to NWS&DW policies, water consumption which greater than 90 units is charged 140 LKR per unit and 1600 LKR of monthly service charge ('National Water Supply and Drainage Board', 2018)
Average cost of water per year = {(247.6325x140) +1600} ×12 = 435,222.60 LKR
Cost of the proposed project = 1,989,014.70 LKR
Let the project cost recovery period to be "Y"

$$Y = \frac{\text{project cost} + (\text{project cost} \times \text{inflation} \times Y)}{\text{average annual water cost}}$$

$$Y = \frac{1{,}989{,}014.70 + (1{,}989{,}014.70 \times 0.08 \times Y)}{435{,}222.60}$$

Y = 7.2037, take as 7.2 years
Project cost recovery period is about 7.2 years

Discussion

Though the rainwater harvesting systems are not extremely used in Sri Lanka, they are commonly used in developed countries. In most of the cases roof top rainwater harvesting systems are used in the buildings for flushing purposes without having any water purification process. The proposed system can easily be developed to such uses doing some adjustments.

The proposed system includes a storage tank which is to be imported from an Australian company. In there, actual scenarios were considered which are done in an actual project, but if the tank can be locally produced with expected outcomes, huge amount of money saving can be done. On the other hand, importing a well-produced storage tank will save time (spend in production and design phase) and maintenance supervision will be given by the company itself. Anyhow, the cost is negligible comparatively the benefits of the project which is capable of recovering the cost within 7.2 years

Conclusions

The rainwater harvesting system which can be seen under sustainable development, is one of the best solutions to minimize the wastage of potable water in landscaping projects and results in considerable financial benefits. Though the proposed system is based on as actual proposed project for Wayamba University of Sri Lanka, this would be a fine encouragement model which can be easily adaptable for the rest of universities in Sri Lanka and the world.
Not only for the landscaping projects, but also for the same model is appropriate in day-to-day gardening, washing and flushing tasks where there is no need of water purification. When it comes to the nest stage, same model can be used for the fulfilment of the drinking water demand inserting some effective purification methods.

This model can directly be used to encourage Sri Lankan society to make use of the precious rain water. Minor type rainwater harvesting system similar to the described method can be used for domestic water demand of gardening, vehicle washing and sanitary facilities.

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Kasun Nandapala

Poster ID-01

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2.4.3

Unpublished Papers

Points are not claimed under this section

2.5

Patents and Inventions

2.5(1)

National Patent No. 17803 - A Heat Insulation System for Flat Roof Slabs

Please Refer the Next Page

SRI LANKA

PATENT

'o All to Whom These Presents Shall Come.

/hereas, there has been presented to the Director General of Intellectual Property an plication for the grant of a patent for an invention as described, shown and claimed the documents annexed and attached hereto, and made part hereof,

ereas, the application is in compliance with all the requirements of the Intellectual perty Act No. 36 of 2003 and Regulations made thereunder,

tent is hereby granted to the person whose name, address and other relevant mation are given hereunder and the patentee shall have for a period of twenty from the filing date of the application for the patent, subject to the provisions of tellectual Property Act No. 36 of 2003, the exclusive rights to exploit the ed invention, to assign or transmit the patent and to conclude licence contracts ng the patent.

entee who intends to keep the patent in force is required to renew the patent he expiration of two years from the date of the grant of the patent and each ng year during the term of the patent.

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First day of **September** of the year
Two Thousand and Sixteen

Director General of Intellectual Property

National Intellectual Property Office of Sri Lanka

Patent No : *17803*

Date of Filing : *23/07/2014*

Name (s) and Address (es) of the owner of patent:

Dr. Rangika Umesh Halwatura
No: 2A, Lesly Perera Mawatha, Kaluthara North and
Mr. Manamendra Patabendige Kasun Chinthaka Nandapala
96, Eriyagoda Estate, Pallawa-Dampitiya Road, Hanhamunawa, Maspotha.

Name (s) and Address (es) of the Inventor (s) :

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Mr. Manamendra Patabendige Kasun Chinthaka Nandapala (whose legal address is 96, Eriyagoda Estate, Pallawa-Dampitiya Road, Hanhamunawa, Maspotha).

Title of the Invention:

A HEAT INSULATION SYSTEM FOR FLAT ROOF SLABS

Priority Date, if any: --

International Patent Classification (IPC): E04B 7/22

International Search Report: --

No: --

Date: --

Issued by: --

National Intellectual Property Office
Sri Lanka

2.5(2)

National Patent No. 18880 - Bamboo Heat Insulation Panels for Flat Roof Slabs

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PATENT

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ereas, the application is in compliance with all the requirements of the Intellectual erty Act No. 36 of 2003 and Regulations made thereunder,

ent is hereby granted to the person whose name, address and other relevant ation are given hereunder and the patentee shall have for a period of twenty y om the filing date of the application for the patent, subject to the provisions of th llectual Property Act No. 36 of 2003, the exclusive rights to exploit the pa invention, to assign or transmit the patent and to conclude licence contracts inv the patent.

The e who intends to keep the patent in force is required to renew the patent befo xpiration of two years from the date of the grant of the patent and each succe ear during the term of the patent.

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First day of **August** of the year
Two Thousand and Seventeen

Director General of Intellectual Property

llectual Property Office of Sri Lanka

Patent No : *18880*

Date of Filing : *08/07/2016*

Name (s) and Address (es) of the owner of patent:

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Name (s) and Address (es) of the Inventor (s) :

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Title of the Invention: *Bamboo heat insulation panels for roof slabs*

Priority Date, if any: --

International Patent Classification (IPC): *E04B 7/20*

International Search Report:

No: --

Date: --

Issued by: --

National Intellectual Property Office
Sri Lanka

2.6

Books and Scholarly Work

2.6.1

Books, scholarly work not submitted for a degree

2.6.1(1)

Madujith Sagara Chandra, Kasun Nandapala, Buddhika Weerasinghe: Vaasthu, Feng-Shui, Traditional Beliefs Vs Civil Engineering. 01/2018; LAMBERT Academic Publishing., ISBN: 978-620-2-05837-7

Please Refer the Next Page

Madujith Sagara Chandra
Dr. Kasun Nandapala
K.A.B. Weerasinghe

Vaasthu, Feng-Shui, Traditional Beliefs Vs Civil Engineering

Madujith Sagara Chandra
Dr. Kasun Nandapala
K.A.B. Weerasinghe

Vaasthu, Feng-Shui, Traditional Beliefs Vs Civil Engineering

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Vaasthu, Feng-Shui, Traditional Beliefs Vs Civil Engineering

Part 01

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DEDICATION

This book is dedicated to my loving parents and each and every teacher, lecturers or any academics who do a great job in teaching and research fields delivering a remarkable service to the students.

ACKNOWLEDGEMENT

Since this book is one of the outcomes of my Masters research, I would like to convey my deepest gratitude to the persons who helped me in that stage also. This is a product of myself, Dr. Kasun Nandapala who is my supervisor, Eng. K.A.B. Weerasinghe and Eng. D.N. Gunasekara.

I must convey my gratitude to Dr. Sumnda Ranasinghe, Mr. D.A. Thevathason and Eng. Pasindu Weerasinghe to the priceless backups.

The helps and supports given by my colleagues, associates and individuals such as Mr. Janaka Priyantha, Mr. Nirmala Madu Sagara, Miss. Kaushi Dissanayaka, Miss Rizna Arooz, should be highly acknowledged.

I would also like to convey my sincere gratitude to my parents for being a strength and encouragement in making this task.

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LIST OF ABRIVIATIONS

BM – Bending Moment

BS – British Standards

CFD – Computational Fluid Dynamics

FEM – Finite Element Modelling

HVAC – Heating Ventilation and Air Condition

SF – Shear Force

CHAPTER 1

1.1. Background of the study

Every being in the world like human beings, all spices of animals, each and every kind of insects or any type of organisms need safe and secure places to dwell. The ultimate purpose of these places is being protected from climate changes and enemy attacks. The most valuable gift, the power of thinking of the human being made them superior to other beings around him (Nehru, 1930). Though the ancient human lived in caves, dens and huts built on top of the huge trees in the jungle hunting animals at the periods when they were savages, gradual evolution converted him into a domestic being called "farmer". As a result of that, people eventually shifted from caves to well-prepared sheltered places (Patra, 2006). With the passage of time, those places were called houses which represent dwelling places for human beings. These are the places which are always suitable for human beings to dwell comfortably and a place that ensures an excellent balance between men and nature which brings peace, happiness, health, wealth and prosperity to the inmates of the house (Koralage Dayarathna, 2010; Ulusoy & Kuyrukcu, 2012).

This house is the place where any family spends most of the important, precious and valuable time of their lives. But it may not the place where people spent many hours of the day, for instances Doctors spend more than half the day at hospitals, Engineers spent weeks, months and years at their working sites and Professors spend much time in the universities, but any of these places are not houses of any of above-mentioned professionals. Since it is the place where people spend the most precious times of their lives with beloved family members , houses are considered as sacred places as shrines (Aponso Kithsiri, 1995; Wattage Jeewa Bhanumathie, 1995). Because of that people are making a huge effort to build their dream house to be matched with each and every desire of them and their family members.

To achieve their goals, people use various types of knowledge resources such as Civil Engineering and Architectural knowledge and traditional Customs and Beliefs in Building Construction. As a result of the development of the Science and Technology, people commonly use Civil Engineering and Architectural concepts for house construction activities. These concepts refer to the designation of space and creating and constructing the space needed for creating the day to day lives of people easy and the science of construction and designing the built environment. Although the science and technology is in a high standard at the contemporary time, the shadows of traditional customs and beliefs can be seen in most of the fields like building constructions, town and country planning, medicine etc. likewise e, people have not totally abandoned the customs and beliefs in house construction, which are consist of different branches like Ancient Architecture, Astronomy, Vaasthu Shastra and Feng-Shui. These beliefs in Building Construction which initiated from experiences obtained by day to day activities of our ancestors, highly affected the lives of the people and spread through the society. They were lasting for years and years, remain with slight changes proving that they have mixed with society.

The customs and beliefs which have been adapted in the building construction from ancient times, get differ with respect to the climatic, religious and cultural parameters. Some of them have got labelled as superstitions and have been rejected by the society; but most of them that came from generation to generation with slight differences are still in practise proving that there are some sort of importance of them (Frenando W.L.R., 1998; Guptha, 2015; Koranteng, Afram, & Ayeke, 2015; Rudski, 2003)

Almost all the customs and beliefs in building construction have been influenced by and based on Vaasthu Shastra, Feng-Shui and various religious considerations of the society. Vaasthu Shastra which belongs the period 1500-1000 BC (Glazer, 1978; Guptha, 2015; Koranteng et al., 2015; Mak & Thomas Ng, 2005; Patra, 2006, 2009; Ranjeet.P et al., 2016) is an ancient Indian knowledge as well as a science of Architecture, planning and designing. The word Vaasthu originally derived from the keyword “vas” meaning of dwell or dwelling place, likewise, the term Vaasthu conveys a place of human dwelling more than a single household life. Feng-Shui is an ancient Chinese wisdom literally means “wind and water”, influence the layout and the design of cities and buildings (Mak & Thomas Ng, 2005). The concept of the Feng-Shui born in China and spread in western countries and it can be seen all around the world now.

The Vaasthu and Feng-Shui concepts have spread in Asian countries more than in Western and European Countries. The main reason can be the religious influence. However, the Western People have their own customs and beliefs regarding building construction, mainly for house construction, but they are not as strong as the concepts of Asian Countries. The reason for that difference is the spiritual values which were attributed to the religious influences of Asian countries (Ranawaka Leelananda A.R., 2015; Manawadu S., 2014; Weerasinghe K.A.B., Janaka K.G., and Galappaththi M.P., 2011)

In the modern world, Civil Engineering and Architectural concepts are mainly and mostly applicable to any construction activity. Those concepts refer to the designation of space and it is the art of creating and constructing the space needed for making the day to day lives of human beings easy using the science of construction and designing

2.6.2

Books, scholarly work submitted for a degree

Points are not claimed under this

section

2.7

Monographs

Points are not claimed under this

section

2.8

Chapters in Books, scholarly work

Points are not claimed under this

section

2.9

Editing of collections of Essays other than journals

Points are not claimed under this

section

2.10

Editing of classical works

Points are not claimed under this

section

2.11

Translations of monographs/books for supplementary reading

Points are not claimed under this

section

2.12

Editing of Journals

Points are not claimed under this

section

2.13

Creative work in literature, culture and arts relevant to the academic discipline of applicant

2.13(1)

Article published on "The Green Guardian" Magazine vol 3 issue 2 (Special Edition on Ecosystem Restoration) on "Let us Pause... Let Nature Breathe..." published on 11/06/2021

Please Refer the Next Page

GREEN BUILDING COUNCIL OF SRI LANKA

THE GREEN GUARDIAN

Vol. 03 | Issue 02

NEWSLETTER OF THE GREEN BUILDING COUNCIL OF SRI LANKA

WORLD ENVIRONMENT DAY

GBCSL ENVIRONMENT WEEK

5TH - 11TH JUNE 2021

ECOSYSTEM RESTORATION

Let us Pause... Let Nature Breathe...

Let me start with a brutal statement. Covid 19 pandemic has its own merits!!!

Anshul Chopra is a nature photographer from Jalandhar in Punjab. He enjoys his breakfast leisurely owing to the lockdown due to the pandemic. He hears a delightful cry from upstairs: "Look! The mountains are visible". He climbs upstairs. For the first time in his lifetime, he sees the mountain range of the Himalayas 200 kilometers away. Breathtaking sight has been there behind the smog. This is not months after the lockdown, but just twelve days!!!

Sea Turtles are known to be endangered for as long as we remember. Thus, we protect them. However, do we? Juno Beach in Florida is a known site for laying eggs of sea turtles. They lay their eggs leisurely now. Not on usual numbers, but on a staggeringly high scale. Furthermore, the chance of survival of the newborn has drastically increased due to the absence of us. Have we been protecting them all along? Highly doubtful. This is just one month after the closure.

Humpback whales had to share the water with noisy ships in Alaska for the known history. We just watch, not disturbing them. However, don't we? They now have water on their own. The water is 25 times quieter now. Scientists hear voices that they have never heard, the voices of whales. Mother communicates with her calf. Now the mother can leave her offspring to play while she hunts, knowing that she can hear if the calf is in trouble. Therefore, the nursing whale is well fed now. The calves are safe and growing. Best time ever!!!

A resident in Saint Lucia, South Africa, is filling gas to his car. Not as frequently as usual due to the closure due to the pandemic. He suddenly turns back. A hippo!!! A real, well-alive hippo is having a jog it seems. How free must he be feeling!!!

Sika Deer has been going along well with humans in Nara, Japan. It has adapted well and blended with society. It walks among tourists, shows a bit of respect, nods its head, and earns a rice bran cracker. Oops!!! Tourists have stopped. For once, it seems like the absence of humans may have a negative impact. However, does it? An elder deer steps out. Walks along the road and crosses a few with his herd! He navigates them to a place where they were feeding ages ago. Not bran crackers, but real grass as it is intended to be. Healthier and tastier! And less plastic in the area means less possibility of death due to that. No! Human absence is not negative.

South Africa is hit hard by the pandemic. Tourism industry has almost collapsed. In Mpumalanga, there lies an abandoned lodge. Abandoned by humans, that is. Vervet monkeys seize the opportunity and reserve the lodge. Full board, free-of-charge!

Not only them, but an entire wildlife ecosystem develops. There comes a guest disrupting their leisurely stay, a leopard! He starts to hunt even during the day. Survival of the fittest is occurring. He is the new owner of the lodge now. It's his kingdom. Nature rejuvenates!

At the very top of the wish list of anybody who visits Maasai Mara, Kenya, is to photograph a hunting cheetah. Being the fastest sprinter in the world, it can hunt. However, owing to its lean body, it's not the strongest among the predators. It has to somehow take the hunt to its cubs or call the cubs to the hunt. The hunt is too heavy, it can't be carried. He calls for his cubs, but in such a way that the predators are not hunted. It calls, but cubs cannot hear, because a lot of vehicles, walkie-talkies, voices, and all sorts of noises trump. Therefore, one out of three cubs survives in general. All of a sudden, the country is locked down. No vehicles, no walkie-talkies, no voices, and no noise. Cheetah calls the cubs; they respond in a flash. Cubs survive. Hence, doubtlessly more cheetahs in near future!

These are a few of the observations that nature lovers have made all across the globe. I look at my backyard, I see it and I feel it. Anybody will see the rejuvenation; we only have to watch. Post the industrial revolution; we have been exponentially disrupting the balance of the world, thinking that we are more powerful than nature itself. However, nature has given us an opportunity to pause and look back while it breathes.

Sustainability is such a hefty, bombastic word to understand. Thus, we don't try to.

I look out of my window. I can see empty roads, which are normally full of vehicular traffic. Between my window and the road, there is a papaya tree. There is a juicy fruit that we have forgotten to pluck. I have now been watching that fruit for a week now. I can see a number of birds that I haven't even seen in my lifetime and squirrels (and surely there should be ants too) have been consuming it for a week now. It would have been in our bellies in one meal had we not forgotten to pluck it.

I am not sure whether I should be embarrassed to learn what 'sustainability' is from those 'animals'.

Let me reiterate, 'Covid 19 Pandemic has its own merits'. Top of them for me is that it has given us a chance to pause and think.

Let us pause… Let nature breathe…

(Inspiration by the documentary 'The Year Earth Changed' produced by BBC Studios Natural History Unit Production)

Dr. Kasun Nandapala
Head, Department of Construction Technology,
University of Vocational Technology
Outstanding Green Professional of the Year - 2020

2.14

Other Creative work

Points are not claimed under this

section

2.15

Citations

Points are not claimed under this

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Section 3

Contributions to University and National /International Development

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3.2.6 Participation as President/Secretary/Treasurer in University Teacher Unions, or in the capacity in University Alumni Association at national level . . . 365

3.2.7 Membership of Boards of Management/Boards of Study in other Universities/Higher Educational Institutes . . . 367

3.2.8 President/Secretary of a Professional/Academic Association at National level . . . 369

3.1

Dissemination of knowledge

3.1.1

Text Books

Points are not claimed under this

section

3.1.2

Books to be used for supplementary reading

Points are not claimed under this

section

3.1.3

Translations of books

Points are not claimed under this

section

3.1.4

Documentary orations

3.1.4(1)

Invited Speaker - Public Webinar on Harithawath Niwasak: Sustainable Home organized by the Green Building Council of Sri Lanka

Please Refer the Next Page

GREEN BUILDING COUNCIL OF SRI LANKA

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පාසල් දරුවන් උදෙසාම ශ්‍රී ලංකා හරිත ගොඩනැගීම් කවුන්සිලය විසින්
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https://forms.gle/5r8R7doEmDvKiVvs6

නොමිලේ විද්‍යුත් සහතිකපතක් පිරිනමනු ලැබේ.

විමසීම් :- සේමිණි හසන්ති - 076 0196949 ඊ-මේල් - cpd.gbcsl@gmail.com

GREEN BUILDING COUNCIL OF SRI LANKA (GBCSL)
120/10, "Vidya Mandiraya", Vidya Mawatha, Colombo 07, Sri Lanka
Tel:+94 112679130/+94 773147877, email:office@srilankagbc.org
srilankagbc@gmail.com , Web : www.srilankagbc.org

06.08.2020

100A1/1,
University Quarters, University of Vocational Technology,
Kandawala Road, Ratmalana,
SriLanka.

Dear Dr. Kasun Nandapala.

Letter of Appreciation

We are pleased to place on record our sincere gratitude to you for your great contribution in our endeavour to promote environmental sustainability, by conducting an informative and motivational webinar for school children on 'Harithawath Niwasak: Sustainable Home" on 24th May, 2020 on our invitation.

The participants of the event have sent their feedbacks confirming the resourcefulness and the exceptional value of your presentation. We would like to sincerely appreciate your kindness in volunteering your time and sharing your treasured knowledge and experiences with us.

We look forward to receiving your cooperation and assistance in all of our endeavours to protect environment and to ensure the future wellbeing of our Motherland.

Yours sincerely,

Prof. Ranjith Dissanayake
Chairman
Green Building Council of Sri Lanka

3.1.4(2)

Invited Speaker on ”How to Present Your Research in 10 Minutes” - Pre-conference workshop of the TIDAC Research Symposium, 2024

Please Refer the Next Page

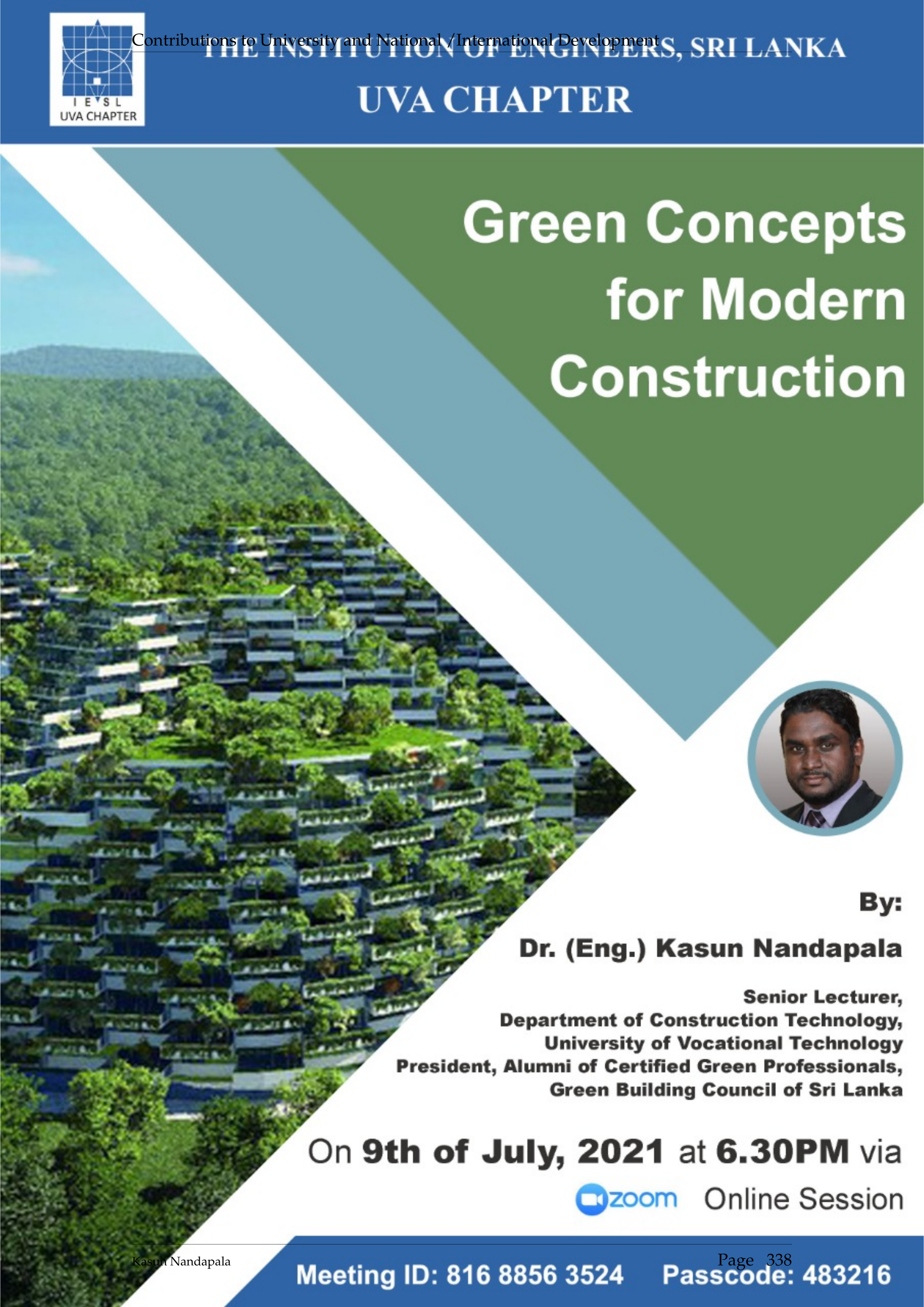
Points are not claimed under this

section

3.1.4(3)

Invited Speaker - Green Concept for Modern Construction by Institude to Engineers, Sri Lanka (Uva Chapter)

Please Refer the Next Page



THE INSTITUTION OF ENGINEERS, SRI LANKA
UVA CHAPTER
I E S L
UVA CHAPTER
Green Concepts for Modern Construction
By:
Dr. (Eng.) Kasun Nandapala
Senior Lecturer,
Department of Construction Technology,
University of Vocational Technology
President, Alumni of Certified Green Professionals,
Green Building Council of Sri Lanka
On 9th of July, 2021 at 6.30PM via
zoom Online Session
Meeting ID: 816 8856 3524 Passcode: 483216

THE INSTITUTION OF ENGINEERS, SRI LANKA
UVA CHAPTER

IESL
UVA CHAPTER

My Number : IESLUVA/2021/20 Date : 9th of July, 2021

Dr.(Eng.)Kasun Nandapala,
Senior Lecturer,
Department of Construction Technology,
University of Vocational Technology, Colombo

09/07/2021

Dear sir,

Appreciation of your contribution to the Institution of Engineers, Sri Lanka-Uva Chapter

On behalf of the Institution of Engineers, Sri Lanka-Uva Chapter, we wish to thank you whole heartedly and convey our gratitude for being the resource person for the online seminar on "Green Concept for Modern Construction" held on 9th of July, 2021.

We appreciate the promptness and friendly manner shown in accepting our invitation and dealing with our request, even amidst your busy schedule. Your presentation was very factual and lucid.

We hope you will provide your valuble expertice for the benefit of our members in the future too.

Thanking you.
Sincerely,

....
Eng.Chathura Sanjeewa
Secretary,
The Institution of Engineers, Sri Lanka – Uva Chapter

Copy:

1) Eng.Nelson Jayathilake, Chairman, The Institution of Engineers, Sri Lanka – Uva Chapter : f.y.i.p.

Chairman
Eng.N.Jayathilake

Office : 057-2222350
Mobile : 071-1485037
Fax : 057-2222350
E-mail : pushpakumaranelson@yahoo.com
Address : Office of Director of Irrigation, Police Road, Bandarawela

Secretary
Eng.W.G.Chathura Sanjeewa

Office : 055-2222405
Mobile : 071-0439010
Fax : 055-2228140
E-mail : chatsanjwb@gmail.com
Address : National Water Supply & Drainage Board, Mediriya Road, Badulla

Treasurer
Eng. S.D.Achintha.S.Peiris

Office : 055-2222217
Mobile : 071-1249918
Fax : 055-2222218
E-mail : achinthasanjeewa@gmail.com
Address : Deputy Chief Secretary (Eng. Services)'s office, Pingarawa,Badulla

3.1.4(4)

Invited Speaker - "A Green Home, A Green Tomorrow" organized by Leo Club of Panadura Heritage

Please Refer the Next Page


Public Webinar
"හරිත නිවසක්, හරිත හෙටක්"
29th January 2022
at 08.00 pm
via
zoom
Join Zoom Meeting through:
Meeting ID: 821 8742 6826
Passcode: Ibe
Organized by
ALUMNI
Alumni of Certified
Green Professionals
LIONS
INTERNATIONAL
Panadura Heritage
Lions Club
• Guest Speaker •
Dr. Kasun Nandapala
President
Alumni of Certified Green Professionals

3.1.4(5)

Invited Speaker - "Green Concept for Infrastructure" organized by Leo Club of University of Colombo

Please Refer the Next Page

LEO DISTRICT 306 A1
LEO CLUB OF UNIVERSITY OF COLOMBO
FACULTY OF ARTS
SRI LANKA

April 26, 2021.

Dr. Kasun Nandapala,
President,
Alumni Certified Green Professionals,
Green Building Council of Sri Lanka.

Dear Sir,

Thanking Letter for being our Guest Speaker of the Project 'Ecotopia Phase III Session 2'

We hope this letter finds you well.

We wish to deliver our utmost regards, respect and admiration as well as, gratitude towards you for blessing us with your presence at **'Ecotopia Phase III Session 2'**, which was held on **26th of April 2021 from 6.00 pm onwards via Zoom App** under the topic ***"Green Concept for Infrastructure"*** and for the invaluable session.

We are deeply grateful that you could take time out for us from your busy schedule and we hope that this kindness, support will remain in the future.

Yours Sincerely,

Leo Malmi Kuruppu,
President (2020/21),
Leo Club of University of Colombo,
Faculty of Arts.

President	Leo Malmi Kuruppu	+94 767210011	malmikuruppu4@gmail.com
Secretary	Leo Kavindya de Silva	+94 705670492	kavindyadesilva1020@gmail.com
Leo Club Advisor	Lion Dilshan Ravisara	+94 712471766	draviz119@gmail.com
Senior Treasurer	Dr.Ajith Balasooriya	+94 718384112	ajithbalasooriya@inr.cmb.ac.lk

3.1.4(6)

Invited Speaker - ”Introductory Workshop on Meeting Climate Change and Sustainable Development through Green Technologies” organized by Green Building Council of Sri Lanka

Please Refer the Next Page

INTRODUCTORY WORKSHOP ON MEETING CLIMATE CHANGE AND SUSTAINABLE DEVELOPMENT THROUGH GREEN TECHNOLOGIES

CONDUCTED BY GREEN BUILDING COUNCIL OF SRI LANKA

RESOURCE PEOPLE:

Prof. Sarath Kotagama
Emeritus Professor
University of Colombo

Prof. Ranjith Dissanayake
Senior Professor Uni. of Peradeniya
Chairman Green Building Council

Dr. Kasun Nandapala
Department of Construction Technology,
University of Vocational Technology.

WORKSHOP CONTENT:

- ✓ Impacts of Climate Change and Environmental Pollution
- ✓ Concept of Sustainability and Its Implementation
- ✓ Sustainable Development Goals (SDG)
- ✓ Sustainable Development Through Green Technologies

FOR WHOM:

Students expecting to start tertiary education on 2021 (Government or Private) in Engineering, Environmental Science, Applied Science, Agriculture, Technology, Physical Science or related fields.

4th of December 2020
9.00 AM -12.00PM

FREE OF CHARGE

zoom

Registration Link: https://forms.gle/WsUdirARPbHBrda96

www. | Find us on facebook | Follow us on Instagram

Phone Number: 0760196949 | Email - cpd.gbcsl@gmail.com

Green Building Council of Sri Lanka 120/10, Vidya Mandiraya, Vidya Mawatha, Colombo 07

3.1.5

Academic/Professional Distinctions

3.1.5(1)

Finalist of the 3MT Thesis Competition organized by the Sri Lankan Association of Young Scientists, Coordinating Secretariat for Science, Technology and Innovation and National Science Foundation

Please Refer the Next Page

This is to certify that

KASUN NANDAPALA

was a finalist in the

SLAYS 3-Minutes Thesis Competition

Jointly Organized by
Sri Lankan Academy of Young Scientists (SLAYS)
and National Science Foundation of Sri Lanka (NSF)

in collaboration with
Coordinating Secretariat for Science Technology and Innovation (COSTI)

held on 1st March 2017
at Hilton Colombo Residences, Colombo, Sri Lanka.

Dr. Tharanga Thoradeniya
(President – SLAYS)

Chaminda
Dr. Chamindri Witharana
(Secretary – SLAYS)

3.1.5(2)

Outstanding Green Professional of the Year - 2020 Awarded by

Green Building Council of Sri Lanka

Please Refer the Next Page

GREEN
BUILDING
COUNCIL OF
SRI LANKA

This is to certify that

Outstanding Green Professional of the Year Award - 2020

Is awarded to

Dr. M. P. K. C. Nandapala

in recognition of his commendable commitment
and impressive achievements in transforming
the construction industry in Sri Lanka
with green building practices and application of green technology.

Awarded on the 27th of December 2020
at the

Green Building Awards Ceremony 2020

held in Colombo, Sri Lanka

Dr. Locana Gunaratna
Chairman, Accreditation Board
Green Building Council of Sri Lanka

Prof. Ranjith Dissanayake
Chairman
Green Building Council of Sri Lanka

3.2

University and National Development Activities

3.2.1

Vice-Chancellor

Points are not claimed under this

section

3.2.2

Dean of a Faculty/Director of a Research Institute

3.2.2(1)

Director - Admission, Accreditation & Quality Assurance from

20th August, 2021

Please Refer the Next Page

වෘත්තීය තාක්ෂණ විශ්වවිද්‍යාලය
வாழ்க்கைத்தொழில்சார் தொழில்நுட்பவியல் பல்கலைக்கழகம்
University of Vocational Technology
100, කඳවල, රත්මලාන. இல.100, கந்தவல, இரத்மலானை. No. 100, Kandawala, Ratmalana. Sri Lanka.

My No: UoVT/EST 1/2/AP/DAAQA 20.08.2021

Dr. M P K C Nandapala,
Senior Lecturer Gr. (II),
Faculty of Engineering Technology.

Dear Dr. Nandapala,

APPOINTMENT TO THE POST OF DIRECTOR ADMISSION, ACCREDITATION AND QUALITY ASSURANCE

I am pleased to inform you that subject to the approval of the Board of Governors of the University, you have been appointed as the Director, Admission, Accreditation and Quality Assurance of the University of Vocational Technology as per the provision 16 (I) of the University of Vocational Technology Act No.31 of 2008. This appointment is for a period of 03 years w.e.f. 20th August 2021. The provisions of clause 16 of the above Act will apply for this appointment.

This appointment is in addition to your present duties as a Senior Lecturer (Grade II) and the Head of Department, Department of Construction Technology in the Faculty of Engineering Technology, University of Vocational Technology.

Please acknowledge the acceptance of this appointment.

Senior Professor Ranjith Premalal De Silva
Vice Chancellor
University of Vocational Technology
No. 100, Kandawala,
Ratmalana, Sri Lanka.

Senior Professor Ranjith Premalal De Silva
Vice Chancellor

Copies:

1. Director General
2. Dean -Faculty of Engineering Tech./Faculty of Education/Faculty of Information Communication Tech./Faculty of Industrial Tech.
3. Director (SDC/Finance)
4. Auditor General
5. Internal Auditor
6. Personal File

උප කුලපති | துணைவேந்தர் | Vice Chancellor | Tel: 011 2630704 | සිසු සේවා කේන්ද්‍රය | மாணவர் சேவைகள் நிலையம் | Student Service Centre. | Tel: 011 2630701
අධ්‍යක්ෂ ජනරාල් | பணிப்பாளர் நாயகம் | Director General | Tel: 011 2630706 | කාර්යාලය | பொது அலுவலகம் | General Office | Tel: 011 2630700
web : www.univotec.ac.lk E-mail : univotec@univotec.ac.lk Fax : 011 2630705

3.2.3

Head of a Department of a University or any other Institution

3.2.3(1)

Head, Department of Construction Technology from 1st May 2018

to 28th February, 2023

Please Refer the Next Page

වෘත්තීය තාක්ෂණ විශ්වවිද්‍යාලය
வாழ்க்கைத்தொழில்சார் தொழில்நுட்பவியல் பல்கலைக்கழகம்
University of Vocational Technology
UNIVOTEC
100, කඳවල, රත්මලාන. இல.100, கந்தவல, இரத்மலானை. No. 100, Kandawala, Ratmalana. Sri Lanka.

My No: UOVT/AC/MPKCN/517 27.04.2018

Through Dean/ Faculty of Industrial & Vocational Technology

Dr. M P K C Nandapala
Lecturer
Department of Construction Technology

Dear Dr. Nandapala

Appointing as the Head, Department of Construction Technology

I am pleased to inform you, that you have been appointed as the Head - Department of Construction Technology of the University in pursuance of the powers vested in it by paragraph (vii) of section 28 of the University of Vocational Technology Act No.31 of 2008, with effect from 1st May 2018 to three years onwards.

This appointment is additional to your present duties and responsibilities as a Lecturer of the Faculty of Industrial & Vocational Technology.

Your cooperation, dedication and commitment in this regard highly appreciated.

Prof. G L D Wickramasinghe
Vice Chancellor

CC:

1. Director General
2. Dean – FIVT/FTT
3. Director Finance
4. Director AAQA
5. Director MIS
6. Senior Assistant Librarian
7. Senior Assistant Registrar- Examination
8. Assistant Registrar – Faculty / Establishment / Admin
9. Statistical Officer
10. Internal Auditor
11. Personal File

LETTER OF ACCEPTANCE

The Vice Chancellor,
University of Vocational Technology

With reference to the Vice Chancellor's letter No .... dated .... I accept the appointment with effect from .... on the terms and conditions specified in the letter of appointment.

.... Date

.... Signature

උප කුලපති / துணைவேந்தர் / Vice Chancellor Tel: 011 2630704
අධ්‍යක්ෂ ජනරාල් / பணிப்பாளர் நாயகம் / Director General Tel: 011 2630706
ශිෂ්‍ය සේවා කේන්ද්‍රය / மாணவர் சேவைகள் நிலையம் / Student Service Centre. Tel: 011 2630701
කාර්යාලය / பொது அலுவலகம் / General Office Tel: 011 2630700
web : www.univotec.ac.lk E-mail : univotec@univotec.ac.lk Fax : 011 2630705

වෘත්තීය තාක්ෂණ විශ්වවිද්‍යාලය
வாழ்க்கைத்தொழில்சார் தொழில்நுட்பவியல் பல்கலைக்கழகம்
University of Vocational Technology
100, කඳවල, රත්මලාන. இல.100, கந்தவல, இரத்மலானை. No. 100, Kandawala, Ratmalana. Sri Lanka.

My No: UOVT/EST 1-2/AL(HOD) 22.04.2021

Dr. M P K C Nandapala
Senior Lecturer – Grade II
Department of Construction Technology

Dear Dr. Nandapala

Appointing as the Head, Department of Construction Technology

I am pleased to inform you, that you have been appointed as the Head - Department of Construction Technology of the University with effect from 03rd May 2021 for a period of three (03) years.

This appointment is in addition to your present duties and responsibilities as a Senior Lecturer of the Faculty of Engineering Technology.

Your cooperation, dedication and commitment in this regard is highly appreciated.

Senior Professor Ranjith Premalal De Silva
Vice Chancellor

Copies:

1. Director General
2. Dean – Faculty of Engineering Tech./ Faculty of Education/ Faculty of Information Tech./ Faculty of Industrial Tech.
3. Director (SDC/Finance/AAQA/MIS- Acting)
4. Senior Assistant Librarian
5. Senior Assistant Registrar- Examination
6. Assistant Registrar – Faculty / Establishment / Admin
7. Statistical Officer
8. Internal Auditor
9. Personal File

LETTER OF ACCEPTANCE

The Vice Chancellor,
University of Vocational Technology

With reference to the Vice Chancellor's letter No ……………………………………….. dated …………………….. I accept the appointment with effect from …………………..... on the terms and conditions specified in the letter of appointment.

………………………… …………………………
Date Signature

උප කුලපති / අධ්‍යක්ෂ ජනරාල් — துணைவேந்தர் / பணிப்பாளர் நாயகம் — Vice Chancellor Tel: 011 2630704 / Director General Tel: 011 2630706
ශිෂ්‍ය සේවා කේන්ද්‍රය / කාර්යාලය — மாணவர் சேவைகள் நிலையம் / பொது அலுவலகம் — Student Service Centre. Tel: 011 26307 / General Office Tel: 011 26307
web : www.univotec.ac.lk E-mail : univotec@univotec.ac.lk Fax : 011 2630705

3.2.4

Course Co-coordinator /Project Co-coordinator for Postgraduate courses

Points are not claimed under this

section

3.2.5

Student Counselor/Career Guidance Counselor/Warden of a Residential Hall

Points are not claimed under this

section

3.2.6

Participation as President/Secretary/Treasurer in University Teacher Unions, or in the capacity in University Alumni Association at national level

Points are not claimed under this

section

3.2.7

Membership of Boards of Management/Boards of Study in other Universities/Higher Educational Institutes

Points are not claimed under this

section

3.2.8

President/Secretary of a Professional/Academic Association at National level

3.2.8(1)

President, Alumni of Certified Green Professionals, Green Building Council of Sri Lanka 2020/2021

Please Refer the Next Page

Points are not claimed under this

section